Draft Total Maximum Daily Load of Total Phosphorus for White Island Pond

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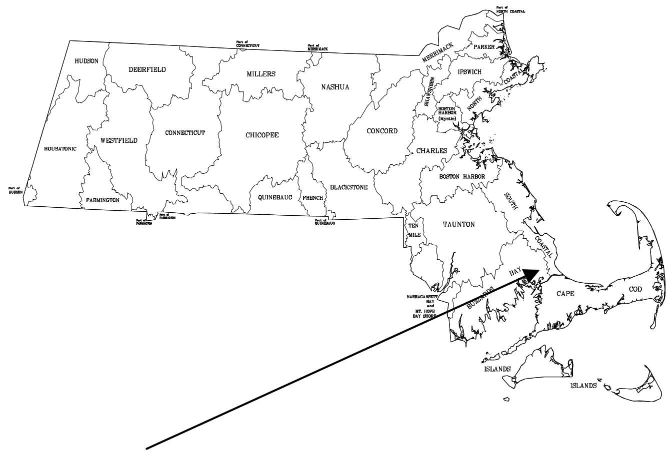

Location of White Island Pond within Buzzards Bay Watershed in Massachusetts.

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http://www.mass.gov/dep/water/resources/tmdls.htm.

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Front Cover

Photograph of the White Island Pond, Plymouth showing bright bluegreen cyanobacterial bloom on the East Basin and northern shore and Cranberry Bogs located on north shore taken July 29, 2007. Ezekiel Pond is also shown as the dark clear lake to the lower right. ©2009 Tele Atlas Google Earth (http://maps.google.com/maps?ll=41.812082,-70.617218&z=15&t=h&hl=en).

Executive Summary

The Massachusetts Department of Environmental Protection (MassDEP) is responsible for monitoring the waters of the Commonwealth, identifying those waters that are impaired, and developing a plan to bring them back into compliance with the Massachusetts Surface Water Quality Standards. The list of impaired waters also referred to as category 5 of the State Integrated List of Waters or the "303d list" identifies river, lake, and coastal waters and the reason for impairment. All impaired waters listed in category 5 require the development of a TMDL report. The current and proposed integrated list and further explanation can be found at http://www.mass.gov/dep/water/resources/tmdls.htm.

Once a water body is identified as impaired, MassDEP is required by the Federal Clean Water Act (CWA) to essentially develop a "pollution budget" designed to restore the health of the impaired body of water. The process of developing this budget, generally referred to as a Total Maximum Daily Load (TMDL), includes identifying the source(s) of the pollutant from direct discharges (point sources) and indirect discharges (non-point sources), determining the maximum amount of the pollutant that can be discharged to a specific water body to meet water quality standards, and developing a plan to meet that goal.

This report develops a total phosphorus TMDL for White Island Pond, East Basin and West Basin in the Buzzards Bay Watershed in Plymouth and Wareham Massachusetts. The lakes are listed as impaired (category 5), on the "Massachusetts Year 2006 Integrated List of Waters" for nutrients, organic enrichment/low DO and noxious aquatic plants, with the East Basin also listed for turbidity. In freshwater systems the primary nutrient known to accelerate eutrophication is phosphorus. This report will satisfy the requirement of a TMDL for White Island Pond. In order to prevent further degradation in water quality and to ensure that each lake meets state water quality standards, the TMDL establishes a phosphorus limit for the lake and outlines actions to achieve that goal.

The two basins are similar in size and depth and are bordered by similar density of residential housing. The most notable difference between the two basins is the direct discharge of two major commercial cranberry bogs into the north end of East Basin. Water quality surveys have shown that the East Basin has consistently higher total phosphorus (TP) concentrations, exhibits frequent algal blooms, and does not meet the guideline for transparency (1.2 meters (m) for Secchi disk transparency). The West Basin also has somewhat elevated total phosphorus with less severe algal blooms and currently does meet the 1.2 m Secchi disk transparency guideline. The lakes are seepage lakes that are hydraulically connected and are modeled as one system with an overall average total phosphorus target set at 0.019 mg/l. The total maximum daily load is estimated as a combined load for the two-basin lake system.

Total Phosphorus Targets

Segment ID	Lake Name	Lake Area	Current Total Phosphorus (mg/l)	Target Total Phosphorus (mg/l)
MA95166	White Island Pond East basin	167 ac	0.081	0.019 (whole lake average)
MA95173	White Island Pond West basin	124 ac	0.034	

A mass balance approach using available data supplemented with nutrient export rates from the literature was used to estimate the current load of total phosphorus of 539 kg/year. The summation of non-agricultural sources accounts for 30 percent of the total load and is fairly evenly distributed between natural groundwater, atmospheric deposition, home septic systems, and recycling from internal sediments. Direct discharges from the commercial cranberry bogs are estimated to be the major source of phosphorus to the ponds, and account for 70 percent of the total phosphorus load. The target load of 147 kg/year (or 0.40 kg/day) was determined from a suite of lake models calibrated to achieve an average in-lake total phosphorus concentration of 0.019mg/l as shown in the table below. Although the TMDL must be expressed on a daily basis, the implementation and administrative decisions should rely on achieving the annual TMDL load which is more appropriate for this slow flushing seepage lake.

White Island Pond (East and West Basins) Phosphorus TMDL Load Allocation

Source	Current Total Phosphorus Loading (kg/yr)	Target Total Phosphorus Load Allocation (kg/yr) and (percent reduction)
Load Allocation		
Groundwater	50	50 (0%)
Precipitation	35	35 (0%)
Home Septic systems	56	28 (50%)
Internal Sediment	18	5 (72%)
Makepeace Bogs	180	9 (95%)
Federal Furnace Bogs	200	10 (95%)
Additional Margin of Safety	0	9 (NA)
Total	539	147 (72%)

The implementation of the TMDL focuses on major reductions in loading from the cranberry bogs, combined with significant reductions from home septic systems. The major implementation can be achieved by a combination of best management practices (BMPs) including reducing the phosphorus fertilizer rates, reducing volumes of discharge water and reducing concentrations of total phosphorus in the discharge water.

Over time, the home septic systems will be updated to Title 5 (State Environmental Code, 310 CMR 15.000) systems and it is recommended that the Board of Health act quickly to bring all non-compliant systems into compliance. Additional controls on stormwater from construction and development in the towns of Wareham and Plymouth will be achieved as part of the Phase II stormwater permits issued by the United States Environmental Protection Agency (USEPA) and the Massachusetts Stormwater Management Regulations, 314 CMR 21.00 (DRAFT).

The successful implementation of this TMDL will require cooperative support from Federal agencies including USEPA and the Natural Resources Conservation Service (NRCS), as well as the cranberry growers, MassDEP, local volunteers, lake and watershed associations, and local officials in municipal government. Funding support to aid in implementation of this TMDL is available on a competitive basis under various state programs including the Section 319 Grant Program administered by MassDEP and federal funding for cranberry growers via the Environmental Quality Incentive Program (EQIP) offered by NRCS.

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Programmatic Background and Rationale

Section 303(d) of the Federal Clean Water Act requires each state to (1) identify waters for which effluent limitations normally required are not stringent enough to attain water quality standards and (2) to establish Total Maximum Daily Loads (TMDLs) for such waters for the pollutants of concern. TMDLs may also be applied to waters threatened by excessive pollutant loadings. The TMDL establishes the allowable pollutant loading from all contributing sources that is necessary to achieve the applicable water quality standards. TMDLs determinations must account for seasonal variability and include a margin of safety (MOS) to account for uncertainty of how pollutant loadings may impact the receiving water's quality. This report will be submitted to the USEPA as a TMDL under Section 303d of the Federal Clean Water Act, 40 CFR 130.7. After public comment and final approval by the USEPA, the TMDL can be used as a basis for State and Federal permitting and regulatory decisions. The report will also serve as a general guide for future implementation activities such as grant funding of best management practices (BMPs). Information on watershed planning in Massachusetts is available on the web at http://www.mass.gov/dep/water/waterres.htm.

The programmatic background summary given below is intended to be general in nature and the issues described may or may not apply to the specific waterbody in question. The management of eutrophic freshwater lakes is typically based on a study of the nutrient sources and loads to the lakes and usually focuses on phosphorus as the important (or limiting) nutrient (Cooke et al., 2005). For TMDLs, the phosphorus loads estimated from the study can be compared to total phosphorus loadings estimated from a suite of different published lake models. A target concentration to meet Water Quality Standards is selected and a target yearly load of phosphorus is calculated for the lake. The phosphorus TMDL is established to control eutrophication in the water column, however additional plant management may be needed. A total phosphorus TMDL is established to meet Massachusetts Surface Water Quality Standards, and to maintain a minimum of 4-foot visibility in surface waters for safe recreational use (which is equivalent to the 1.2 m Secchi disc transparency). The successful implementation of this TMDL will require cooperative support from the public including lake and watershed associations, local officials and municipal governments in the form of education, funding and local enforcement. In some cases, additional funding support is available under various state programs including the MassDEP Section 319 (nonpoint source grants) and the State Revolving Fund Program (SRF); see watershed grants listed in http://mass.gov/dep/water/grants.htm

Nutrient Enrichment: Nutrients are a requirement of life, but in excess they can create water quality problems. Lakes are ephemeral features of the landscape and over geological time most tend to fill with sediments and associated nutrients as they make a transition from lake to marsh to dry land. However, this natural successional ("aging") process can be and often is accelerated through the activities of humans, especially through development in the watershed. For some highly productive lakes with developed watersheds, it is not easy to separate natural succession from "culturally induced" effects. Nonetheless, all feasible steps should be taken to reduce the impacts from cultural activities. The following discussion summarizes the current understanding of how nutrients influence the growth of algae and macrophytes (aquatic plants), the time scale used in the studies, the type of models applied and the data collection methods used to create a nutrient budget. A brief description of the rationale for choosing a target load (the TMDL) as well as a brief discussion of implementation and management options is presented. A more detailed description of fertilizer and water usage in commercial cranberry bogs is provided in Appendix III.

A detailed description of the current understanding of limnology (the study of lakes and freshwaters) and management of lakes and reservoirs can be found in Wetzel (1983), Cooke et al., (2005) and Holdren et al., 2001. To prevent cultural enrichment it is important to examine the nutrients required for growth of phytoplankton (algae) and macrophytes. The limiting nutrient is typically the one in shortest supply relative to the nutrient requirements of the plants. The ratio of nitrogen (N) to phosphorus (P) in both algae and macrophyte biomass is typically about 7 by weight or 16 by atomic ratio (Vallentyne, 1974). Observations of relatively high N/P ratios in water suggests P is most often limiting and careful reviews of numerous experimental studies have concluded that phosphorus is a limiting nutrient in most freshwater lakes (Likens, 1972; Schindler and Fee, 1974). Most diagnostic/feasibility studies of Massachusetts lakes also indicate phosphorus as the limiting nutrient. Even in cases where excess phosphorus has led to nitrogen limitation, previous experience has shown that it is easier, more cost-effective and more ecologically sound to control phosphorus than nitrogen. The reasons include the fact that phosphorus is related to terrestrial sources and does not have a significant atmospheric source as does nitrogen (e.g., nitrates in precipitation). Thus, non-point sources of phosphorus can be managed more effectively by best management practices (BMPs). In addition, phosphorus is relatively easy to control in point source discharges. Finally, phosphorus does not have a gaseous phase, while the atmosphere is a nearly limitless source of nitrogen gas that can be fixed by some blue-green algae, (i.e. cyanobacteria) potentially resulting in toxic blooms. For all of the reasons noted above, phosphorus is chosen as the critical element to control freshwater eutrophication, particularly for algal dominated lakes or in lakes threatened with excessive nutrient loading.

There is a direct link between phosphorus loading and algal biomass (expressed as chlorophyll a) in algae dominated lakes (Vollenweider, 1976). The situation is more complex in macrophyte-dominated lakes where the rooted aquatic macrophytes may obtain most of the required nutrients from the sediments. In organic, nutrient-rich sediments, the plants may be limited more by light or physical constraints such as water movement than by nutrients. In such cases, it is difficult to separate the effects of sediment deposition, which reduce depth and extend the littoral zone, from the effects of increased nutrients, especially phosphorus, associated with the sediments. In Massachusetts, high densities of aquatic macrophytes are typically limited to depths less than ten feet and to lakes where organic rich sediments are found (Mattson et al., 2004). Thus, the response of rooted macrophytes to reductions in nutrients in the overlying water will be much weaker and much slower than the response of algae or non-rooted macrophytes, which rely on the water column for their nutrients. In algal or non-rooted macrophyte dominated systems, nutrient reduction in the water column can be expected to control growth with a lag time related to the hydraulic flushing rate of the system. In lakes dominated by rooted macrophytes, additional, direct control measures such as harvesting, herbicides or drawdowns will be required to realize reductions in plant biomass within a reasonably short time scale. In both cases, however, nutrient control is essential since any reduction in one component (either rooted macrophytes or phytoplankton) may result in a proportionate increase in the other due to the relaxation of competition for light and nutrients. In addition, it is critical to establish a TMDL so that future development around the lake will not impair water quality. It is far easier to prevent nutrients from causing eutrophication than to attempt to restore a eutrophic lake. The first step in nutrient control is to calculate the current nutrient loading rate or nutrient budget for the lake.

Nutrient budgets: Nutrient budgets and loading rates in lakes are determined on a yearly basis because lakes tend to accumulate nutrients as well as algal and macrophyte biomass over long time periods compared to rivers which constantly flush components downstream. In cases of short retention time reservoirs (less than 14 days), nutrient budgets may be developed on a shorter time scale (e.g. monthly budgets from wastewater treatment plants) but the units are expressed on a per year basis in order to be comparable to nonpoint sources estimated from landuse models. Nutrients in lakes can be released from the sediments into the bottom waters during the winter and summer and circulated to the surface during mixing events (typically fall and spring in deep lakes and also during the summer in shallow lakes). Nutrients stored in shallow lake sediments can also be directly used by rooted macrophytes during the growing season. In Massachusetts lakes, peak algal production, or blooms, may begin in the spring and continue during the summer and fall, while macrophyte biomass peaks in late summer. The impairment of uses is usually not severe until summer when macrophyte biomass reaches the surface of the water interfering with boating and swimming. Also, at this time of year the high daytime primary production and high nighttime respiration can cause large fluctuations in dissolved oxygen with critical repercussions for sustaining aquatic life. In addition, oxygen is less soluble in warm summer water as compared to other times of the year. The combination of these factors can drive oxygen to low levels during the summer and may cause fish kills. For these reasons the critical period for use impairment is during the summer, even though the modeling is done on a yearly basis for the reasons explained above.

There are three basic approaches to estimating current nutrient loading rates: the measured mass balance approach; the landuse export modeling approach; and modeling based on the observed in-lake concentration. The measured mass balance approach requires frequent measurements of all fluvial inputs to the lake in terms of flow rates and phosphorus concentrations. The yearly loading is the product of flow (liters per year) times concentration (mg/l), summed over all sources (i.e., all streams and other inputs) and expressed as kg/year. The landuse export approach assumes phosphorus is exported from various land areas at a rate dependent on the type of landuse. The yearly loading is the sum of the product of landuse area (Ha) times the export coefficient (in kg/Ha/yr). In some cases a combined or modified approach using both methods is used. In-lake phosphorus models provide an indirect method of estimating loading but do not provide information on the particular sources of input; however, this approach can be used in conjunction with other methods to validate results. The mass balance method is generally considered to be more accurate, but also more time consuming and more costly due to the field sampling and analysis. For this reason, the mass balance results are used whenever possible. If a previous diagnostic/ feasibility study or mass balance budget is not available, then a landuse export model, such as Reckhow et al., (1980) or the NPSLAKE model (Mattson and Isaac, 1999) can be used to estimate nutrient loading.

Target Load: Once the current nutrient loading rate is identified, a new, lower rate of nutrient loading must be established which will meet surface water quality standards for the lake. This target load or TMDL can be set in a variety of ways. Usually a target concentration in the lake is established and the new load must be reduced to achieve the lower concentration. This target nutrient concentration may be established by a water quality model that relates phosphorus concentrations to water quality required to maintain designated uses including swimming (where 4 feet visibility has been a guidance value). Alternatively, the target concentration may be set based on concentrations observed in background reference lakes for similar lake types or from concentration ranges found in lakes within the same ecological region (or sub-ecoregion). In cases of impoundments or lakes with rapid flushing times (e.g., less than 14 days), somewhat higher phosphorus targets may be used because the planktonic algae and nutrients are rapidly flushed out of the system and typically do not have time to grow to nuisance conditions in the lake or accumulate in the sediments. In the case of seepage lakes (with no inlet streams) they may naturally have lower phosphorus targets, particularly if the lakes are clear water rather than dark or tea colored lakes.

Various models (equations) have been used for predicting productivity or total phosphorus concentrations in lakes from analysis of phosphorus loads. These models typically take into consideration the waterbody's hydraulic loading rate and some factor to account for settling and storage of phosphorus in the lake sediments. Among the more well known metrics are those of Vollenweider (1975), Kirchner and Dillon (1975), Chapra (1975), Larsen and Mercier (1975) and Jones and Bachmann (1976). These models are used to calculate the Total Maximum Daily Load or TMDL, in kilograms of the nutrient per day or per year that will result in the target concentration in the lake being achieved. The TMDL must account for the uncertainty in the estimates of the phosphorus loads from the sources identified above by including a "margin of safety". The margin of safety can be specifically included, and/or included in the selection of a conservative phosphorus target, and/or included as part of conservative assumptions used to develop the TMDL. In addition, a simple mass balance equation (model) of total load divided by total water input, may also be used to establish the minimum load (assuming no settling or loss of phosphorus) that could explain the observed concentration in the lake.

After the target TMDL has been established, the allowed loading of nutrients is apportioned to various sources that may include point sources as well non-point sources such as private septic systems and runoff from various land uses within the watershed. In Massachusetts, few lakes receive direct point source discharges of nutrients. In cases where significant point sources regulated through the National Pollutant Discharge Elimination System (NPDES) program exist upstream of a lake or impoundment, the point source will in most cases be required to use the Highest and Best Practical Treatment (HBPT) to reduce total phosphorus loading. The loads for NPDES point sources are calculated based on current data, not on the permitted discharge loading. New discharge limits at a treatment plant may be computed by applying the percent reduction required to meet the TMDL to the current loads. The new permitted concentrations of total phosphorus can then be calculated based on total mass loading divided by permitted flow rate for the discharge.

The nutrient non-point source analysis generally will be related to landuse that reflects the extent of development in the watershed. This effort can be facilitated by the use of geographic information systems (GIS) digital maps of the area that can summarize landuse categories within the watershed. This is then combined with nutrient export factors which have been established in numerous published studies. The targeted reductions must be reasonable given the reductions possible with the best available technology and Best Management Practices (BMPs). The first scenario for allocating loads will be based on what is practicable and feasible for each activity and/or landuse to make the effort as equitable as possible.

Seasonality: As the term implies, TMDLs must be expressed as maximum daily loads. However, as specified in 40 CFR 130.2(I), TMDLs may be expressed in other terms as well. For most lakes, it is appropriate and justifiable to express a nutrient TMDL in terms of allowable annual loadings. The annual load should inherently account for seasonal variation if it is protective of the most sensitive time of year. The most sensitive time of year in most lakes occurs during summer, when the frequency and occurrence of nuisance algal blooms and macrophyte growth are typically greatest. Because the phosphorus TMDL was established to be protective of the most environmentally sensitive period (i.e., the summer season), it will also be protective of water quality during all other seasons. Additionally, the targeted reduction in the annual phosphorus load to lakes will result in the application of phosphorus controls that also address seasonal variation. For example, certain control practices such as stabilizing eroding drainage ways or maintaining septic systems will be in place throughout the year while others will be in effect during the times the sources are active (e.g., application of lawn fertilizer).

Implementation: The implementation plan or watershed management plan to achieve the TMDL reductions will vary from lake to lake depending on the type of point source and non-point source loads for a given situation. For non-point source reductions the implementation plan will depend on the type and degree of development in the watershed. While the impacts from development cannot be completely eliminated, they can be minimized by prudent “good housekeeping” practices, known more formally as best management practices (BMPs). Among these BMPs are control of runoff and erosion, well-maintained subsurface wastewater disposal systems and reductions in the use of fertilizers in residential areas, parks, cemeteries and golf courses and agriculture. Activities close to the waterbody and its tributaries merit special attention for following good land management practices. In addition, there are some statewide efforts that provide part of an overall framework. These include the legislation that curbed the phosphorus content of many cleaning agents, revisions to regulations that encourage better maintenance of subsurface disposal systems (Title 5 septic systems), and the Rivers Protection Act that provides for greater protection of land bordering waterbodies. In some cases, structural controls, such as detention ponds, may be used to reduce pollution loads to surface waters.

Although the landuse approach gives an estimate of the magnitude of typical phosphorus export from various landuses, it is important to recognize that non-point source phosphorus pollution comes from many discrete non-point sources within the watershed. Perhaps the most common phosphorus sources in rural areas are associated with soil erosion and use of phosphorus fertilizers. Soils tend to erode most rapidly following land disturbances such as construction, gravel pit operations, tilling of agricultural lands, overgrazing, and trampling by animals or vehicles. Erosion from unpaved roads is also a common problem in rural areas. Soils may erode rapidly where runoff water concentrates into channels and erodes the channel bottom. This may occur where impervious surfaces such as parking lots and roadways direct large volumes of water into ditches which begin to erode from either excessive water drainage or poorly designed ditches and culverts. Any unvegetated drainage way is a likely source of soil erosion. Home septic systems that do not meet Title 5 requirements may also be a source if located close to surface waters.

Discrete sources of nonpoint phosphorus in urban, commercial and industrial areas include a variety of sources that are lumped together as ‘urban runoff’ or ‘stormwater’ and may be considered as point sources under wasteload allocations. As many of these urban sources are difficult to identify the most common methods to control such sources include reduction of impervious surfaces, infiltration, street sweeping and other non-structural BMPS as well as treatment of stormwater runoff by structural controls such as detention ponds when this becomes necessary.

Other sources of phosphorus include phosphorus based lawn fertilizers used in residential areas, parks, cemeteries and golf courses and fertilizers used by agriculture. Manure from animals, especially dairies and other confined animal feeding areas is high in phosphorus. In some cases the manure is inappropriately spread or piled on frozen ground during winter months and the phosphorus can wash into nearby surface waters. Over a period of repeated applications of manure to local agricultural fields, the phosphorus in the manure can saturate the ability of the soil to bind phosphorus, resulting in phosphorus export to surface waters. In some cases, cows and other animals including wildlife such as flocks of ducks and geese may have access to surface waters and cause both erosion and direct deposition of feces to streams and lakes.

Perhaps the most difficult source of phosphorus to account for is the phosphorus recycled within the lake from the lake sediments. In most north temperate lakes, phosphorus that accumulated in the bottom waters of the lake during stratification is mixed into surface waters during spring and fall turnover when the lake mixes. Phosphorus release from shallow lake sediments may be a significant input for several reasons. These reasons include higher microbial activity in shallow warmer waters that can lead to sediment anoxia and the resultant release of iron and associated phosphorus. Phosphorus release may also occur during temporary mixing events such as wind or powerboat caused turbulence or bottom feeding fish, which can resuspend phosphorus rich sediments. Phosphorus can also be released from nutrient ‘pumping’ by rooted aquatic macrophytes as they extract phosphorus from the sediments and excrete phosphorus to the water during seasonal growth and senescence (Cooke et al., 2005; Horne and Goldman, 1994). Shallow lakes also have less water to dilute the phosphorus released from sediment sources and thus the impact on lake water concentrations is higher than in deeper lakes.

The most important factor controlling macrophyte growth appears to be light (Cooke et al., 2005). Due to the typically large mass of nutrients stored in lake sediments, reductions in nutrient loadings by themselves are not expected to reduce macrophyte growth in many macrophyte-dominated lakes, at least not in the short-term. In such cases additional in-lake control methods are generally recommended to directly reduce macrophyte biomass. Lake management techniques for both nutrient control and macrophyte control have been reviewed in "Eutrophication and Aquatic Plant Management in Massachusetts. Final Generic Environmental Impact Report" and the accompanying "Practical Guide" (Mattson et al., 2004; Wagner, 2004) http://www.mass.gov/dcr/waterSupply/lakepond/geir.htm.

The Massachusetts Department of Environmental Protection will support in-lake remediation efforts that are cost-effective, long-term and meet all environmental concerns, however, instituting such measures will be aided by continued Federal (via USEPA), and State grant support.

Financial support for various types of implementation is potentially available on a competitive basis through both the non-point source (319) grants and the state revolving fund (SRF) loan program. The 319 grants require a 40 percent non-federal match of the total project cost although the local match can be through in-kind services such as volunteer efforts. Other sources of funding include the 604b Water Quality Management Planning Grant Program and the Community Septic Management Loan Program. Information on these programs is available in a pamphlet "Grant and Loan Programs – Opportunities for Watershed Protection, Planning and Implementation" through the Massachusetts Department of Environmental Protection, Bureau of Resource Protection; see also http://www.mass.gov/dep/service/grantsfi.htm

Because the lake restoration and improvements can take a long period of time to be realized, follow-up monitoring is essential to measure interim progress toward meeting the water quality goal and guide additional BMP implementation. This can be accomplished through a variety of mechanisms including volunteer efforts. Recommended monitoring may include Secchi disk readings, lake total phosphorus, macrophyte mapping of species distribution and density, visual inspection of any structural BMPs, coordination with Conservation Commission and Board of Health activities and continued education efforts for citizens in the watershed

Waterbody Description and Problem Assessment

White Island Pond, a "Great Pond of Massachusetts" in Plymouth/Wareham is a large 291 acre or 118 Hectare (Ha) natural pond comprised of two major basins: West White Island Pond (124 acres) and East White Island Pond (167 acres) as shown in Figure 1. The basins are unstratified with an overall mean depth of only 2.36 meters (7.74 feet). The lake is a clearwater seepage lake with no permanent stream inlets and the primary source of water for the lake is groundwater and direct precipitation. Such lakes are typically very clear, with very low productivity and high transparency. The White Island Pond contributing watershed is 57 % forested. Residential housing accounts for about 16 % and agricultural landuse is 27% which consists primarily of cranberry growing operations. The highest density of housing is located on the western shoreline of the West Basin (see Figure 1). Plymouth and Wareham both have Notices of Intent for Phase II stormwater NPDES permits for the "urbanized area" as indicated in Figure 2 from the EPA website http://www.epa.gov/region01/npdes/stormwater/ma.html. The East Basin is less developed and it is used as a water supply for flooding and irrigating two large commercial cranberry bogs located on the north shore. Chapter 91 Licenses are required to install and maintain structures such as flumes, pumps and dikes, on Great Ponds in Massachusetts, which includes White Island Pond. Chapter 91 Licenses #1335 and #3501 have been issued to A.D. Makepeace Company and License #1311 has been issued to Federal Furnace Cranberry Company.

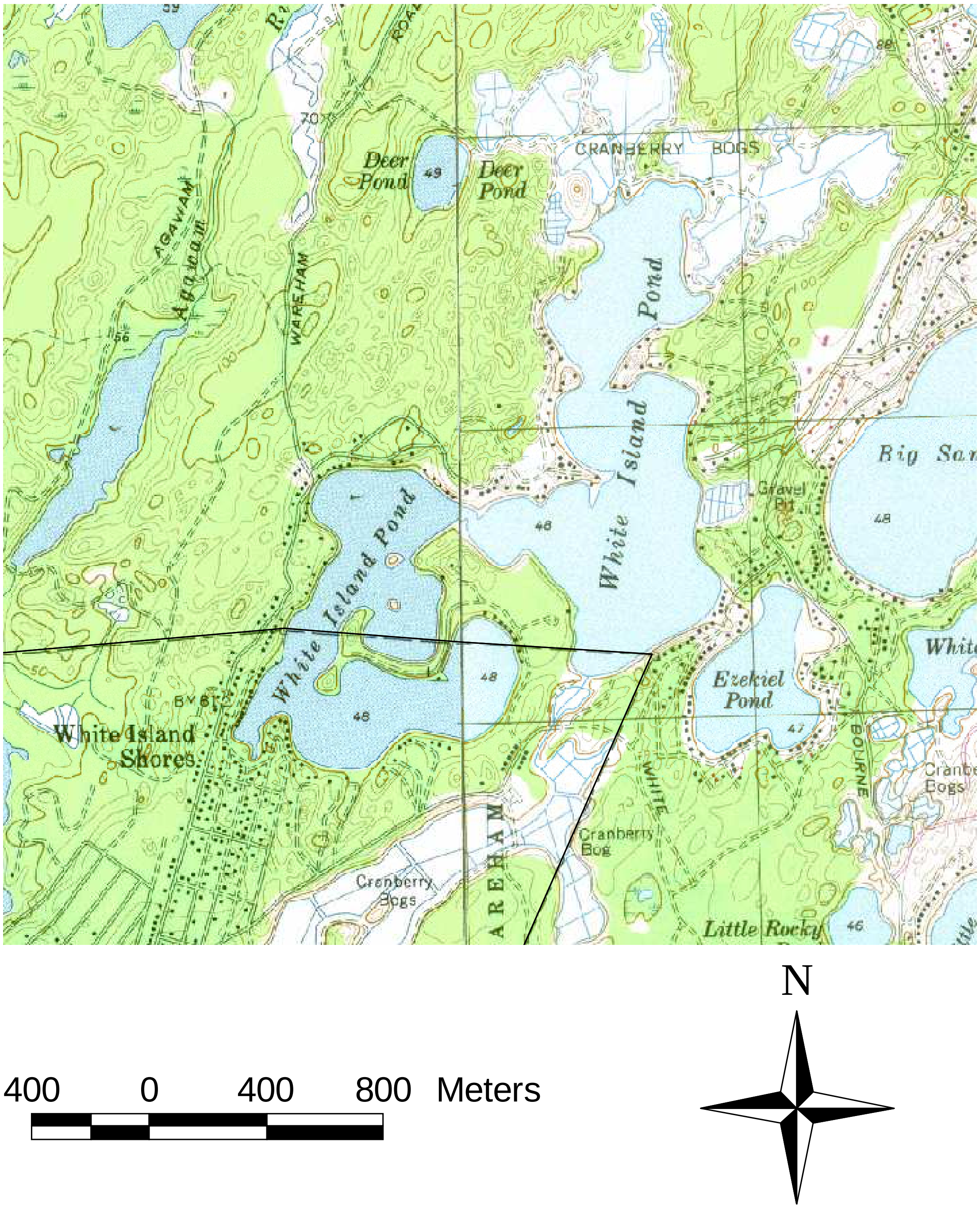


Figure 1. Locus Map of White Island Pond. Nearby Ezekiel Pond is also shown.

Figure 2. Urbanized areas subject to Phase II NPDES permits. The urbanized areas are shown as hatched areas around the pond including areas in towns of Wareham (below and left of dotted line) and Plymouth (above and right of dotted line).

The flow from the pond is manipulated during the year to both irrigate and flood the bogs. A brief description of management practices related to commercial cranberry bog operations is provided in Appendix III.

White Island Pond has a long history of nutrient related impairment of recreation. An early (1976-1978) study of the pond noted degradation of water quality in the form of algal blooms and occasional fish kills. In relative terms however, the pond was fairly clear in the early survey with the East Basin Secchi disk transparency averaging 3.76 m (over 12 feet of visibility) and always better than the 1.2 m swimming guidance. The lake ranged from low to moderately high in phosphorus at that time, with concentrations in the East Basin ranging from 0.01 to 0.05 mg/l with an average of 0.03 mg/l for surface (0-5 feet) samples (Whittaker, 1980). The cranberry bog discharge waters had total phosphorus concentrations ranging between 0.02 and 0.17 mg/l. The study recommended reducing nutrient sources from both the homes and from the cranberry bogs. For home owners the report recommended banning phosphates in detergents (which was done statewide) and septic system maintenance and upgrades for homes (see Title 5 regulations, 310 CMR 15.00). For the cranberry bogs, the report recommended that the owners reevaluate the application of fertilizers and irrigation (Whittaker, 1980).

The lake today is much more eutrophic, with blooms of toxic blue-green cyanobacteria commonly forming scums in the East Basin (see cover photo and see data below). The east basin in particular no longer meets the 1.2 m transparency guideline for safe swimming and phosphorus concentrations in the lake have greatly increased.

Water Quality Standards Violations

Both east and west basins of White Island Pond are listed on the Massachusetts 2006 Integrated List of waters in category 5, for not meeting uses and requiring a TMDL (DWM, 2007 CN 262.1). The East White Island Pond (segment # 95166) is listed for nutrients, organic enrichment/low DO, noxious aquatic plants and turbidity as well as for exotic species (not a pollutant). West White Island Pond (segment #95173) is listed for nutrients, organic enrichment/low DO, noxious aquatic plants as well as for exotic species. West White Island Pond is somewhat more transparent and currently meets the 1.2 m (4 foot) visibility guideline for swimming. The Water Quality Standards are described in the Code of Massachusetts Regulations under sections:

> 314CMR 4.05 (3) b: "These waters are designated as a habitat for aquatic life, and wildlife, and for primary and secondary contact recreation...These waters shall have consistently good aesthetic value.
>
> 1. Dissolved Oxygen:
>   a. Shall not be less than 6.0 mg/l in cold water fisheries nor less than 5.0 mg/l in warm water fisheries unless background conditions are lower;
>   b. natural seasonal and daily variations above this level shall be maintained…

and

> 314CMR 4.05 (5)(a) Aesthetics - All surface waters shall be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris, scum or other matter to form nuisances; produce objectionable odor, color, taste or turbidity; or produce undesirable or nuisance species of aquatic life.

And

314CMR 4.05 (5)(c) Nutrients. Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses and shall not exceed the site specific criteria developed in a TMDL or as otherwise established by the Department pursuant to 314 CMR 4.00. Any existing point source discharge containing nutrients in concentrations that would cause or contribute to cultural eutrophication, including the excessive growth of aquatic plants or algae, in any surface water shall be provided with the most appropriate treatment as determined by the Department, including, where necessary, highest and best practical treatment (HBPT) for POTWs and BAT for non POTWs, to remove such nutrients to ensure protection of existing and designated uses. Human activities that result in the nonpoint source discharge of nutrients to any surface water may be required to be provided with cost effective and reasonable best management practices for nonpoint source control.

Section 314 CMR 4.05(3)(b) 6 also states:

> 6. Color and Turbidity - These waters shall be free from color and turbidity in concentrations or combinations that are aesthetically objectionable or would impair any use assigned to this class.

Exceedence of other Water Quality Thresholds

The Minimum Standards for Bathing Beaches (State Sanitary Code, Chapter VII) established by the Massachusetts Department of Public Health (MDPH) state that swimming and bathing are not permitted at public beaches when there is a lack of water clarity. The water transparency in East White Island Pond has been measured to be less than the MassDEP threshold of 4 feet (1.2 meter) of Secchi disk visibility for support of swimming in the summer of 2007 (see Table 9). West White Island Pond is more transparent and usually meets the 4 foot guidance, however the reduced transparency in the basins results in impairments of the aquatic macrophyte growth.

In addition to the above, bluegreen algae blooms were sampled in the lake and identified as potentially toxic cyanobacteria in June 2007 by MassDEP. In May 2008 MDHP collected water samples from the lake which contained levels of potentially toxic cyanobacteria blooms that exceeded the MDPH thresholds for recreational waters. The three samples were identified as *Anabaena* sp. with a median density of over 700,000 cells/ml by MassDEP staff. White Island Pond was subsequently posted to caution that people and pets should avoid areas of cyanobacteria concentration.

Lake Water Quality Monitoring

Both basins of White Island Pond were monitored during July through September, 2000 as part of a baseline survey. The lake and commercial bog discharges were also sampled in 2007 on a monthly basis from June through October. Results of the lake monitoring are presented in Appendix I.

The 2000 baseline survey consisted of monthly sampling of water at a deep hole station in each basin. The baseline survey included multi-probe profiles of dissolved oxygen, temperature, conductivity and pH. Additional sampling was done to determine Secchi disk transparency, chlorophyll a as an indicator of planktonic algal biomass, apparent color and TP. During the summer of 2000 an aquatic plant survey was conducted. Sampling details are available in the Quality Assurance Project Plan (DWM, 2000). Full results of the survey are available in the Baseline lakes 2000 Technical Memo.

The same deep hole stations were sampled again in 2007 for the multi-probe parameters, Secchi disc transparency, chlorophyll a, color and TP. Samples were also taken of water discharges from the cranberry bogs. Sampling details are available in the Quality Assurance Project Plan (DWM, 2007). The TP, chlorophyll a, and Secchi disk data from 2007 presented here have completed all quality control checks, but additional data may be added as it becomes available. Validated data are presented in Appendix I.

Results of Monitoring White Island Pond

According to the MassDEP DWM year 2000 lake baseline survey data, the East Basin had an average TP concentration of about 0.090 mg/l while the West Basin had an average TP concentration of about 0.046 mg/l. Summer Secchi disk transparency averaged 1.1 m in the East Basin and did not meet the 1.2m guidance for swimming transparency, while the West Basin was somewhat more clear with a Secchi disk of 1.8 m. Chlorophyll a concentrations in the East Basin averaged 35.4 mg/m^3 compared to 10.2 mg/m^3 in the West Basin. The East Basin chlorophyll a concentrations exceeded the 16 mg/m^3 chlorophyll a maximum cited for mesotrophic lakes (Wetzel, 2001) suggesting eutrophic conditions.

The 2000 and 2007 TP data are very similar. The data collected in the summer of 2007 further demonstrated the extent of the nutrient impairment, with numerous blooms of scum-forming blue-green cyanobacteria. Because it is more recent, the 2007 survey data has been used in the development of TMDL calculations detailed below. During the 2007 season, the East Basin never met the 1.2 m transparency guidance needed for swimming while the West Basin was again more transparent with an average of 1.7m of transparency. Chlorophyll a concentrations were somewhat higher compared to the earlier surveys. The West Basin, averaging 19.9 mg/m^3, and the East Basin averaging 41.9 mg/m^3 (indicating eutrophic conditions). The average concentration of total phosphorus in the East Basin surface waters was 0.081 mg/l compared to the 0.03 mg/l measured in the 1970's (described above). The West Basin had an average TP concentration of 0.034 mg/l giving an overall average TP for both basins of 0.057 mg/l. By way of comparison, nearby Ezekiel Pond exhibited clear water, with a TP concentration of only 0.006 mg/l in 2007. According to the commonly used Carlson trophic index (Appendix III), Ezekiel Pond would be oligotrophic (nutrient poor), while White Island Pond varies from eutrophic up to hypereutrophic.

In addition to the chemistry data presented above, the MassDEP staff noted blooms of potentially toxic cyanobacteria in the water of East White Island Pond and the pond was officially posted to caution the public against swimming as noted in the water quality violations noted above. A photo of one of the blooms being collected for identification is shown in Figure 3, below.

Figure 3. Photo of cyanobacteria surface bloom in White Island Pond.

It was also noted that the total phosphorus concentrations in the cranberry bog waters were higher in the 2007 survey as compared to the 1970's results. Two summer discharge samples collected in 2007 at A.D. Makepeace averaged 0.073 mg/l, while 2 summer discharge samples from Federal Furnace averaged 0.47 mg/l. A summary of the MassDEP total phosphorus data for the lake samples (including nearby Ezekiel Pond), the cranberry bog discharge waters, and the groundwater (from literature) are shown as vertical bars in Figure 4.

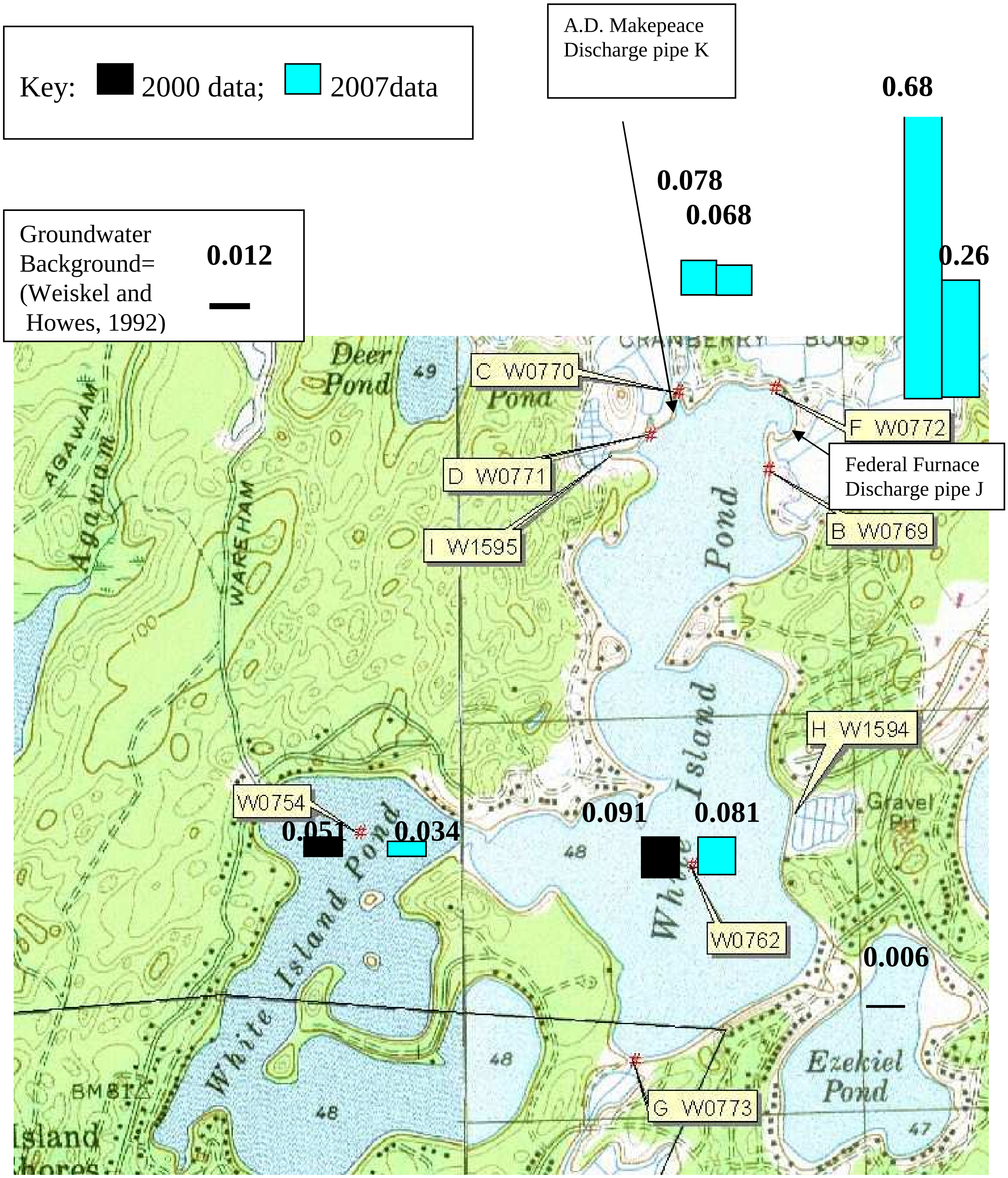
The TP data summary presented in Figure 4 indicates that both East and West White Island Pond are higher in TP than a nearby lake (Ezekiel Pond) and higher than groundwater in the region. The figure also suggests that the TP concentrations are higher in the East Basin where high concentrations of bog waters discharge to the ponds and lower in the West Basin where most of the homes are located. The results suggest that homes are not the cause of the high phosphorus, and suggest the cranberry bogs are likely to be a major source.

These results are supported by an additional 26 cranberry bog discharge samples collected by the White Island Pond Conservation Alliance (WIPCA) from 2006- early 2008 with most samples collected in 2007. Those samples were collected and analyzed promptly at a certified analytical laboratory, Groundwater Analytical. As is typical with cranberry operations those results show moderate TP concentrations during the summer discharges, 0.13 mg/l and 0.45 mg/l for Makepeace and Federal Furnace, respectively, and similar or somewhat higher concentrations during the larger fall harvest discharges with averages of 0.38 and 0.45 mg/l for Makepeace and Federal Furnace , respectively (J. Sullivan, pers.comm. 2008). Although the results from the citizen's group are not used in calculations to develop this TMDL, they do support the MassDEP results noted above.

MassDEP and WIPCA observed the bogs were discharging water to the lake on a regular basis during the summer of 2007, despite the fact that it was not a wet summer. According to the United States Geological Survey (USGS), June and July were in the normal range for runoff in southeastern Massachusetts, and July and September were significantly below average at the USGS gage sites; see:
http://ma.water.usgs.gov/drought/Surface_Water_Maps_for_Water_Year_2007.html.

Thus, the Makepeace and Federal Furnace bogs show characteristics of 'flow-through' bogs that discharge large amounts of water and nutrients to downstream receiving waters. At times the Federal Furnace bogs were observed to pump water from the lake to irrigate the bogs, while simultaneously discharging excess water back to the East Basin (J. Sullivan, WIPCA, pers. comm. 2007). As there are no streams flowing though either the Makepeace or Federal Furnace bog, this suggests that excess groundwater is being pumped off the bogs, resulting in an higher than typical volume of water being discharged to the East Basin from these bogs.

Figure 4. Relative Total Phosphorus concentrations bar graph (mg/l) and sample locations.



The dissolved oxygen (DO) and temperature profiles from 2000 showed that both the East and West basins of White Island Pond were unstratified with temperatures typically less than a degree Celsius different between the surface and the bottom (Figure 5). Although the lake dissolved oxygen was above the WQS of 5 mg/l in the profiles taken in the summer of 2000, an additional profile taken in early summer of 2007 showed low oxygen near the bottom sediments. This may indicate eutrophic conditions in the pond as algae and detritus settle to the bottom of the lake and are decomposed, resulting in low oxygen.

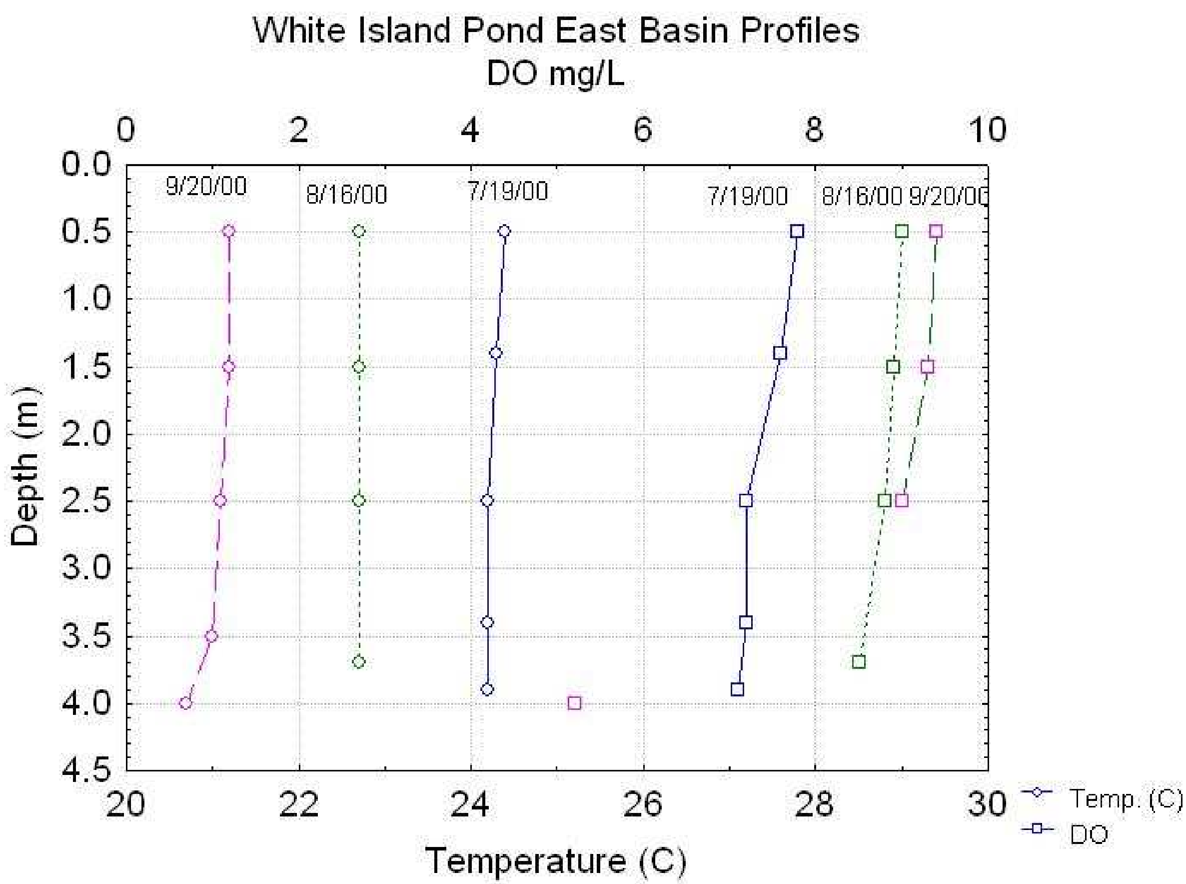


Figure 5. East White Island Pond DO and Temperature Profiles.

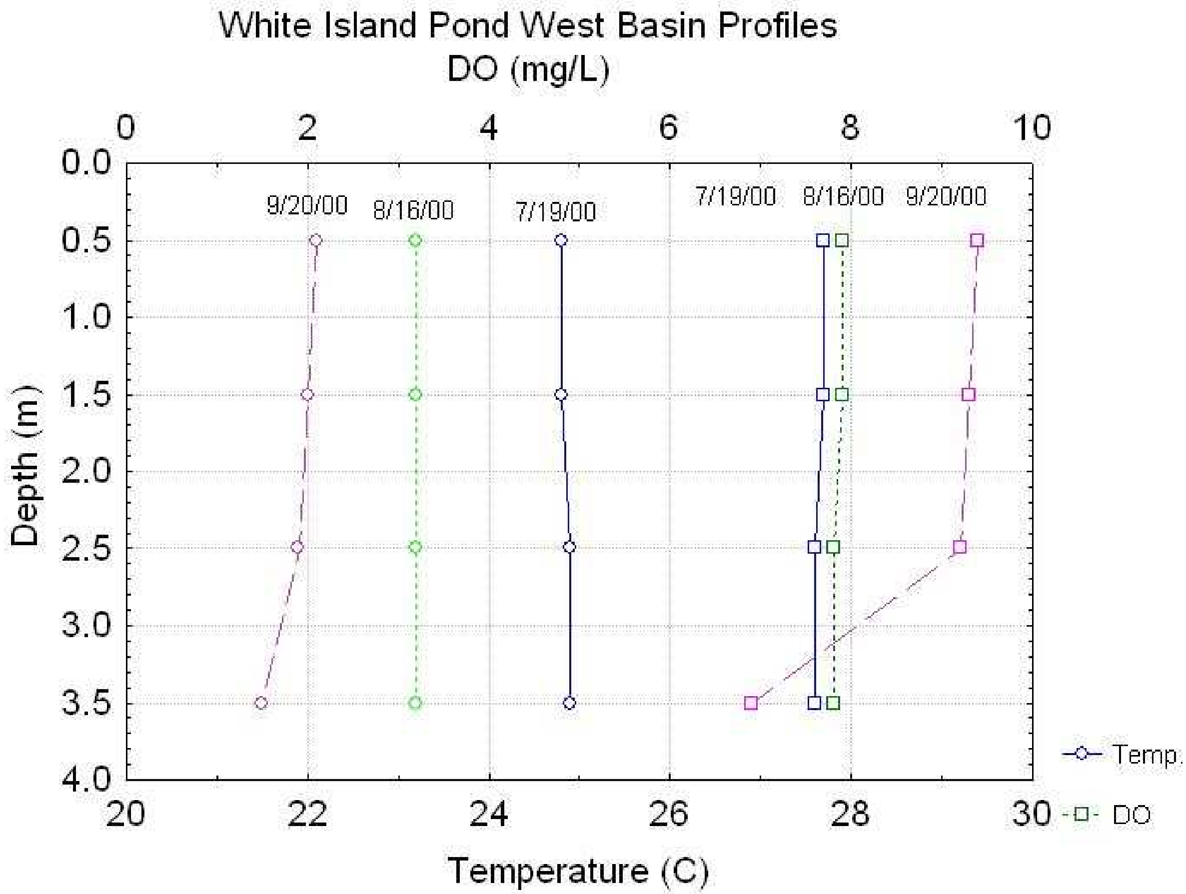


Figure 6. West White Island Pond DO and Temperature Profiles.

The overall plant density in White Island Pond is very sparse in recent surveys compared to plant surveys in the 1970's that noted nuisance conditions caused by dense plant growths in the northern bay of the east basin (Whittaker, 1980). Low plant densities are not uncommon in seepage lakes with mineral sediments but the current low density of plants outside of very shallow areas in this lake suggests light limitation caused by the low transparency of the water as seen in the recent surveys. The frequent algal blooms can shade the submerged aquatic vegetation and reduce the overall biomass.

Hydrologic Budget

There are no permanent tributary streams shown on the USGS quadrangle maps of the area (Figure 1), but the ditches of the Makepeace and Federal Furnace cranberry bogs can discharge to the lake if the boards are removed from the outlets at the end of the dikes. The East Basin has an outlet which flows south through a different set of cranberry bogs. Those bogs are presumed to discharge waters to the south away from the lake and are not discussed in this report. As a seepage lake, White Island Pond is replenished by groundwater and direct precipitation. The commercial cranberry bogs pump water from and discharge water back to the lake, although the exact volumes of water discharged are unknown. A recent study of Massachusetts commercial cranberry bogs reported an annual usage of 8-11 feet per acre (DeMoranville and Howes, (2005).

The area of groundwater contribution (578.1 Ha) to the lake was estimated from groundwater elevations using a USGS model (Hansen and Lapham, 1992) as shown in Figure 7. Using this approach the annual groundwater recharge in the area of White Island Pond is estimated to be 27 inches per year. All of the water recharged from the contributing area was assumed to contribute to the lake. After consultation with USGS scientists who are updating the 1992 model, the annual groundwater contribution was estimated to be 4.2 million m^3 . Precipitation in the region is 47.6 inches per year (NOAA, 1984). When precipitation is multiplied by the surface area of the lake (118 Ha or 291 acres) this accounts for 1.2 million m^3 per year of water recharge per year. Estimated evaporative loses (Ward et al., 2004) from the lake surface reduce the net recharge from precipitation to 0.70 million m^3/year. Thus, the areal water load to the lake surface is estimated to be 4.16 m/year with a flushing rate of 1.76 per year or a residence time of 207 days.

Nutrient Budget Methods

The estimation of nutrient budgets for the ponds involves a comparison of several approaches including:

1. landuse modeling of nutrient loads for both ponds;
2. estimation of phosphorus mass balance using a product of water inputs (flow) and TP concentrations of each source combined with best professional judgment based on literature values for other sources including septic systems and internal sources;
3. lake modeling of nutrient loads for the lake. In order to model the predicted nutrient concentration in the lake a hydrologic (water) budget must also be constructed.

Each of these approaches is discussed below.

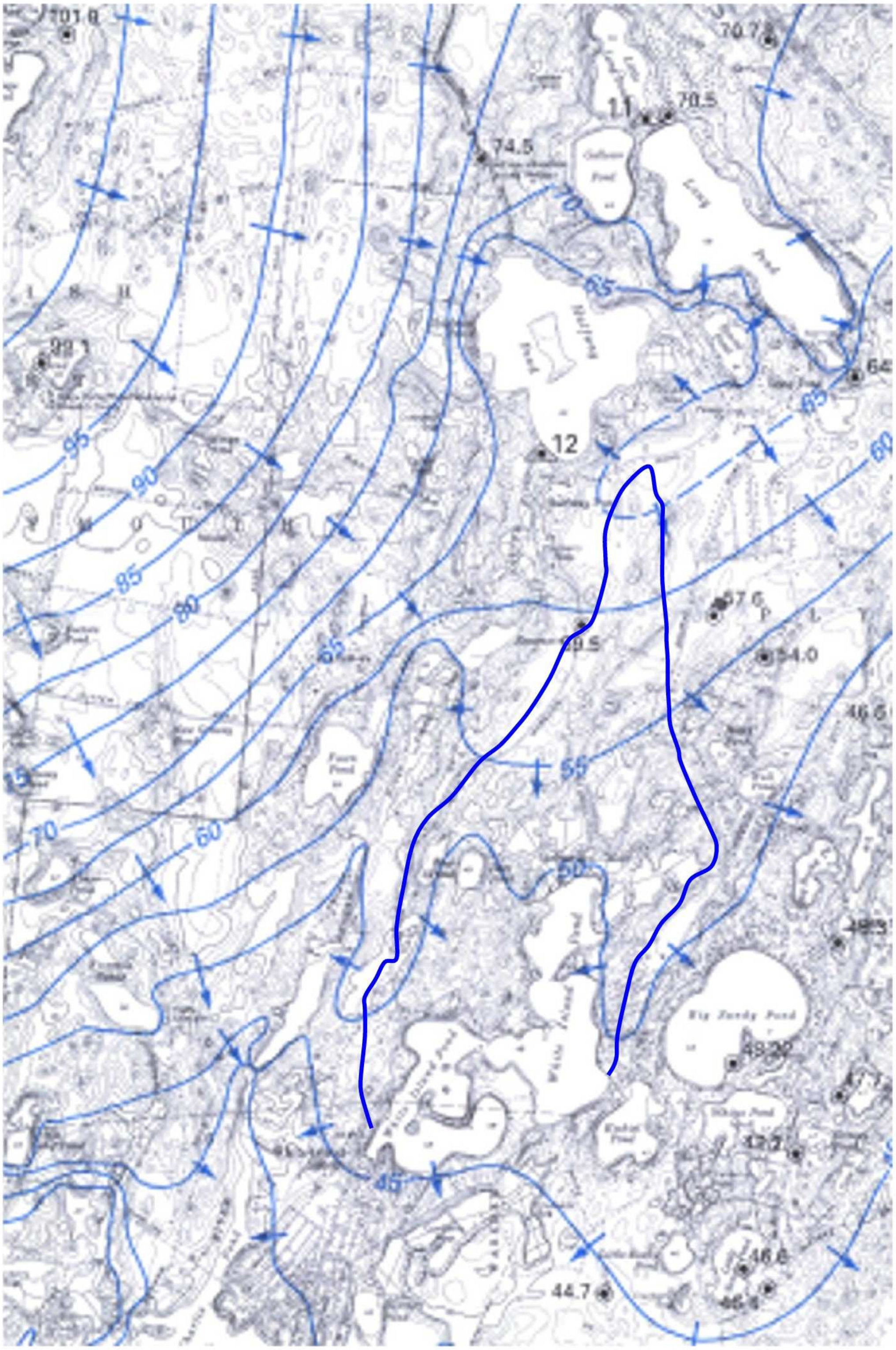


Figure 7. Groundwater contributing area (Hansen and Lapham, 1992).

Landuse Modeling

The NPSLAKE model of Mattson and Isaac (1999) was designed to estimate rates of phosphorus loading from various landuses in the watershed to lakes. Phosphorous inputs from septic systems and other residential uses, such as lawns, are estimated from an export coefficient multiplied by the number of homes within 100 meters of the lake. All coefficients fall within the range of values reported in other studies such as Reckhow et al., (1980). This model takes the area in hectares of land use within three major categories of landuse, forest, urban and rural, and applies an export coefficient to each to predict the annual external loading of phosphorus to the lake from the watershed. However, this landuse export approach assumes that phosphorus from each landuse is delivered to the lake with little attenuation. This assumption may be true for direct, fluvial discharges from bogs but may not apply to other landuse source inputs where infiltration occurs. In Southeastern Massachusetts and the Cape Cod region, the water inputs to the seepage lakes common to the area are dominated by groundwater inputs that have significant attenuation by soil adsorption. Thus the landuse export approach needs to be modified for use in the area surrounding White Island Pond, and the following discussion will focus on a combined, or modified mass balance approach with lake modeling used to validate the results.

Modified Nutrient Mass Balance Approach

The total load of phosphorus to White Island pond was estimated to be 539 kg per year, or approximately 1200 pounds per year, using a modified mass balance approach. The calculation of this load is based on a combination of monitoring data from 2007 and estimated literature loadings for all sources including groundwater, direct atmospheric inputs, discharges from cranberry bogs, septic systems and internal (sediment) sources. The sources and the assumptions used in the calculations are described below.

The phosphorus contributed by groundwater is calculated based on the estimated volume of groundwater entering the pond multiplied by the concentration of phosphorus in groundwater (0.012 mg/l from Weiskel and Howes, 1992). A total of 50 kg/year of phosphorus or approximately 9% of the total phosphorus load is attributed to groundwater. The phosphorus load from direct precipitation is based on the area of the lake multiplied by a loading coefficient of 0.3 kg/ha/year (Reckhow et al., 1980). A total of 35 kg/year or 7% phosphorus is attributed to direct precipitation phosphorus load.

There are two methods to determine phosphorus loadings from cranberry bogs, the cranberry export coefficient based on the work of DeMoranville and Howes, (2005) and Howes and Teal (1995) and the concentration discharge method. The cranberry export coefficient method is the primary means used to develop the TMDL and will be discussed first. Previous studies have shown a large difference in the nutrient discharge from bogs which is dependent upon the hydrology of the bogs (closed vs. flow-through bogs). Closed bogs, such as those studied by the UMass Cranberry Station (DeMoranville and Howes, 2005), typically discharge significant amounts of water in the days following the fall harvest floods, the winter frost prevention floods or the occasional pest control floods in the spring; large discharges in the summer generally do not occur in closed bogs. The flow-through bogs, such as those studied by Howes and Teal (1995), are characterized by streams that actually enter and flow through the bog complex. The phosphorus concentrations and nutrient load from these flow-through type bogs was higher than the closed bogs studied by DeMoranville and Howes (2005). The Makepeace and Federal Furnace bogs were both observed to have frequent discharges of water during the summer via pumping and thus appear to be intermediate between the closed and flow-through bogs. Although neither bog has a stream flowing through it, the bogs appear to have a significant volume of groundwater seepage which needs to be pumped off the bogs on a regular basis. Therefore, two phosphorus loadings will be estimated using the landuse export method; the first is calculated with the high (flow-thru operation) coefficients and the other based on the low (closed operation) export coefficients for bogs. These two estimates will be compared to both the concentration discharge estimates of loading (below) and later compared to lake model estimates of phosphorus loading to the lake.

There are two separate commercial bog operations on the northern shore of the East Basin. The A.D. Makepeace Company cultivates 18.1 Ha of bog and Federal Furnace Cranberry Company cultivates 20.2 Ha. To calculate the "low" export estimate the recent study by the University of Massachusetts Cranberry Station and UMass Dartmouth (DeMoranville and Howes, 2005) for closed bogs is used. Based on the nature of the bogs (older bogs established on organic soils), and the relatively high concentrations of total phosphorus in the discharge waters, an export coefficient of 3.4 kg P/ha/year has been applied to the bogs. Thus, the low estimate is for phosphorus export is 131 kg/year, with Makepeace accounting for 62 kg/year and Federal Furnace accounting for 69 kg/year.

Assuming these same bogs are acting as flow-through bogs, the high landuse export coefficient of 9.9 kg/ha/yr from Howes and Teal (1995) is applied to the bog areas listed above. This results in the "high" phosphorus loading estimates of 180 kg/yr and 200 kg/yr of phosphorus for the Makepeace and Federal Furnace bogs, respectively, for a total of 380 kg/yr.

An alternative estimate of phosphorus loading from the cranberry bogs (the concentration discharge method) can be used to compare to the results of primary landuse export method discussed above. The method is based on the assumption that the bogs discharge about 7.5 acre-feet of water (assuming no evaporation) and the total mass load is the product of the discharge volume times the observed average total phosphorus concentration. The average concentration measured in 2007 from the A.D. Makepeace Company was relatively low at 0.073 mg/l, resulting in a somewhat smaller estimate of 30 kg/year. The average total phosphorus concentration in the Federal Furnace discharge during summer of 2007 was high at 0.47 mg/l, and this results in an estimated load of 217 kg/year. It should be noted that because these bogs were discharging during the summer period they are likely to be discharging more than the nominal 7.5 acre-feet of water and thus the total load estimate of 247 kg/year is probably an underestimate. The estimate does fall between the low and high landuse estimates of 131 kg/yr and 380 kg/year calculated above. , MassDEP did not monitor either fall harvest discharges and winter flood discharges. Previous work has shown that winter discharges are associated with relatively high nutrient loadings (Howes and Teal, 1995) and this is supported by volunteer data showing a high concentration (0.18 mg/l) in winter discharge at White Island Pond (J. Sullivan, WIPCA, pers. comm. 2009).

As a result, it is concluded that flow-thru export coefficients more accurately reflect the operating conditions of the Makepeace and Federal Furnace operations. Therefore, annual phosphorus loadings from cranberry bog discharges are based on landuse export coefficient of 9.9 kg/ha/yr resulting in a cranberry bog annual load of 380 kg or 70% of the total phosphorus, as shown in Table 1.

Although the UMass Cranberry Station recommends phosphorus fertilizer rates of no more than 20 pounds per acre per year, it appears that many farmers exceed this recommendation. Even within the group of cranberry growers who volunteered for a nutrient reduction study, half of the bogs were applying more phosphorus fertilizer than the recommended maximum phosphorus rate at the beginning of the study (DeMoranville and Howes, 2005), sometimes by a factor of two. Similar over-application of phosphorus fertilizer to cranberries has been documented in Massachusetts (Howes and Teal, 1995). Part of the problem was due to the lack of commercial fertilizer mixes with low phosphorous to nitrogen ratios. Since the nutrient reduction study, more commercial fertilizers with lower phosphorous content have become available.

Phosphorus loading attributed to septic system contributions is calculated by taking the average of two export coefficients. First, the NPSLAKE model septic system phosphorus export coefficient of 0.5 kg/house/year was multiplied by the 224 homes located within 100 m of the White Island Pond shoreline to estimate 112 kg P/year for septic systems inputs. This initial estimate appears to be too high for the area based on monitoring results for nearby Ezekiel Pond located about 200 yards southeast of White Island. Like White Island Pond, Ezekiel Pond is a seepage pond. However, residential development is denser around Ezekiel Pond with 62 homes within 100 m of the 1750 m shoreline, resulting in an average linear density of one house every 28 m (90 feet) of shoreline. By comparison White Island Pond has 224 homes within 100 m of its 11,100 m shoreline with a house every 49.5 m (162 feet), with the majority of homes on the clearer West Basin. Although Ezekiel Pond has nearly twice as many homes per unit length of shoreline, it has remarkably clear water, with very low concentrations of total phosphorus (0.006 mg/l) in the surface water and reportedly has never experienced an algal bloom (J. Sullivan, pers. comm. 2007). This information suggests septic system phosphorus is highly attenuated in the soils of the region and that significant phosphorus plumes from the septic systems are not reaching the lakes. In fact, the lake models would predict phosphorus concentration near 0.006 mg/l for White Island Pond only if both internal loading and septic systems and cranberry bog phosphorus inputs were hypothetically set at zero. As a conservative approach it was assumed that soils in contact with leachate from septic systems will eventually saturate with phosphorus over time and eventually leach some phosphorus. Therefore, the average of the two septic system export coefficients was applied for a total load of 56 kg/year for the phosphorus load from septic systems. This would account for 10% of the total phosphorus inputs to White Island Pond. In a separate study of the larger Buttermilk Bay watershed (which includes White Island Pond), Valiela and Costa (1988) noted that gross inputs of phosphorus to the watershed (prior to adsorption and uptake) were dominated by septic systems and agricultural use of fertilizers (mainly cranberry bogs), but it was noted that the septic systems discharge to groundwater (where phosphorus is strongly adsorbed) while it is assumed the cranberry bogs discharge to surface waters with less uptake and adsorption.

In some cases the lake sediments themselves can be a source of phosphorus to the lake. Typically this occurs during periods of anoxia when iron compounds in the sediments are chemically reduced and the phosphate adsorbed to the iron is released to the bottom waters, resulting in higher phosphorus concentrations at the bottom. In shallow lakes, such as White Island Pond, this internal phosphorus can be mixed back to the surface causing additional algal growth. White Island Pond is normally well mixed with adequate oxygen, however, on one of the six dates where oxygen profiles were collected in the two years of sampling, dissolved oxygen concentrations were less than 1 mg/l at a depth approximately 1 m above the sediment surface. This typically indicates the sediments are anoxic. On the same date a higher concentration of total phosphorus was observed in the near bottom water sample compared to the surface, indicating a potential release of phosphorus from the sediments.

The internal anoxic phosphorus release from lake sediments is estimated in two ways: by mass accumulation during temporary stratification, and by anoxic area multiplied by an estimated release rate. The oxygen profile of the bottom was below 1 mg/l in only one of the six dissolved oxygen (DO) profiles collected during the 2000 and 2007 summer visits, and that profile was collected on June 26, 2007. Thus, the days of anoxia were calculated as 1/6th of the summer stratification period. The area below 3.9 m (the depth at which the low oxygen was recorded in both the East and West Basins) was calculated as 102,000 m^2 with a volume below that depth of 48,000 m^3. Using a value of anoxic phosphorus release of 6 $mg/m^2/day$ based on the rationale used for nearby Stetson Pond (BEC. 1993) a phosphorus release of 18 kg/yr is estimated. The second estimate using mass balance calculations is based on the increase in concentration of total phosphorus between the surface and the water near the sediments. The increase in concentration is multiplied by the volume of water below 3.9 m (48,000 m^3) to obtain an estimate of 1.9 kg. The higher value of 18 kg/yr will be assumed to provide liberal estimate of this source. The 18 kg accounts for 3 percent of the total phosphorus load.

The phosphorus nutrient budget calculated by the combined mass balance and export coefficient values for sources is summarized in Table 1 (values may not sum to 100 percent due to rounding). For each source (row), the base unit for the source is multiplied by the appropriate time or volume and the product is multiplied by the appropriate export coefficient to yield the estimated phosphorus load in kg/year.

Table 1. White Island Pond Mass Balance Phosphorus Budget

Source	**Unit or Area (Ha)**	**Time or Volume** (m^3)	TP (**mg/l**)	Export **Coefficient** (**kg/ha/yr**)	Total Phosphorus Load (**kg/yr**)	**Percent** of Total Phosphorus Load (%)
Groundwater	**460**	**4,200,000**	**0.012**		**50**	**9**
Precipitation	**118**	**1,430,000**		**0.3**	**35**	**7**
Makepeace Bogs	**18.17**			**9.9**	**180**	**33**
Federal Furnace Bogs	**20.2**			**9.9**	**200**	**37**
Internal	**10.2**	**30 days**		**21.9**	**18**	**3**
224 Homes with Septic systems				**0.25**	**56**	**10**
Total					**539**	**100**

Lake Model Estimates of Nutrient Loads

Lake models can be used for two purposes, first to validate estimates of existing loads compared to current lake concentrations, and second to develop TMDL loads to meet new target lake concentrations. Although direct mass loading estimates are the most accurate method of constructing nutrient budgets, lake modeling can be used to validate how well the loads agree with the observed concentrations in the lake and to determine if there are missing sources or overestimated sources in the budget. Lake survey data revealed that with the exception of one day noted above (June 26, 2007), there were no differences in the total phosphorus concentrations between the surface and near bottom samples and, therefore, the surface samples were assumed to be representative of overall lake conditions. Because it is difficult to separate the inputs from the East and West Basins, and because the two basins are similar in size, the average of the two ponds is used to represent overall lake concentrations in the model. Assuming our estimates of sources are correct, and the TMDL is fully implemented, the East Basin will improve relatively more than the West Basin, and eventually both basins will have similar, acceptable water quality. Lake models can be used to predict TP from annual phosphorus loads as well as to reverse calculate predicted loads from lake TP concentrations. Rather than relying on a single lake model, a suite of five lake water quality models (Vollenweider (1975), Kirchner and Dillon (1975), Chapra (1975), Larsen and Mercier (1975) and Jones and Bachmann (1976), K. Wagner, pers. comm., 2000), were applied to determine loadings, along with a simple mass balance approach using the recently collected data for the total load and observed average concentration of total phosphorus for White Island Pond. Input data for the models is summarized in Table 2.

The five lake models used were developed and validated on north temperate lakes with relatively long retention times and similar in size and depth to White Island Pond. The reader is referred to original papers for additional details on the models assumptions, and details of calibration and validation. There are no numeric models available to predict the growth of rooted aquatic macrophytes as a function of nutrient loading estimates, therefore the control of nuisance aquatic macrophytes is based on best professional judgment.

Using the five established models and the observed 2007 average concentration of 0.057 mg/l TP, the predicted annual load ranged from 363 to 767 kg/year with an average of 523 kg/yr, which is in good agreement with the modified mass balance estimate of 539 kg/yr, estimated above. Because the lake models agree with the loading estimates we can assume the models are reasonably accurate and all sources have been accounted for. The simple mass balance model (assuming no phosphorus retention in the lake) was slightly lower at 280 kg/year and represents a lower boundary for the true load. Running the models backward with the 539 kg/yr as input, the models predict a range in concentration of 0.4 to 0.85 mg/L with an average of 0.062mg/l. Therefore, these models show good agreement with the observed average lake concentration of 0.057 mg/l TP.

Table 2. Input data for Lake Models of Total Phosphorus

Parameter	Units	Derivation	Value
Lake Total Phosphorus Conc.	mg/l	From data or model	0.057
Annual load	kg/yr		539
Areal Phosphorus Load to Lake	g P/m^2/yr	From data or model	0.46
Influent (Inflow) Total Phosphorus	mg/l	From data	0.059
Effluent (Outlet) Total Phosphorus	mg/l	From data	0.057
Inflow, total	m^3/yr	From data	4.90E+06
Lake Area	m^2	From data	1.18E+06
Lake Volume	m^3	From data	2.78E+06
Mean Depth	m	Volume/area	2.36
Flushing Rate	flushings/yr	Inflow/volume	1.76
Suspended Fraction	no units	Effluent TP/Influent TP	1.0
Areal Water Load	m/yr	Z(F)	4.2
Settling Velocity	m	Z(S)	2.2
Retention Coefficient (from TP)	no units	(TPin-TPout)/TPin	0.033
Retention Coefficient (settling rate)	no units	((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs)	0.65
Retention Coefficient (flushing rate)	no units	$1/(1+F^{0.5})$	0.43
Water retention time	Days	365/(Inflow/volume)	207

Table 3. Final Results of Lake Models for White Island Pond using 539 kg/year input

Method Name	Method Formula	Predicted Concentration (mg/L)	Predicted Load (G/M2/Yr)	Predicted Load (Kg/Yr)
Mass Balance	TP=L/(Z(F))*1000	0.101		
(minimum possible load)	L=TP(Z)(F)/1000		0.24	280
Kirchner-Dillon 1975	TP=L(1-Rp)/(Z(F))*1000	0.040		
(K-D)	L=TP(Z)(F)/(1-Rp)/1000		0.65	767
Vollenweider 1975	TP=L/(Z(S+F))*1000	0.085		
(V)	L=TP(Z)(S+F)/1000		0.31	363
Chapra	TP=L(1-R)/(Z(F)*1000	0.057		
(C)	L=TP(Z)(F)/(1-R)/1000		0.46	539
Larsen-Mercier 1976	TP=L(1-Rlm)/(Z(F))*1000	0.063		
(L-M)	L=TP(Z)(F)/(1-Rlm)/1000		0.42	491
Jones-Bachmann 1976	TP=0.84(L)/(Z(0.65+F))*1000	0.067		
(J-B)	L=TP(Z)(0.65+F)/0.84/1000		0.39	457
Average of Model Values		0.062		
(without mass balance)			0.44	523
Measured in White Island Pond		0.057		
Mass Balance Input to models			0.42	539

TMDL Total Phosphorus Targets

As the term implies, TMDLs are expressed as maximum daily loads. However, as specified in 40 CFR 130.2(I), TMDLs may also be expressed in other terms when appropriate. For these cases, the TMDLs are expressed in terms of allowable annual loadings of phosphorus because the growth of phytoplankton and macrophytes responds to changes in annual, as well as daily, loadings of nutrients. The target phosphorus concentration must be set low enough to ensure the lake meets all designated uses. Generally, all uses for typical warm water fisheries lakes (including swimming, boating and aesthetics) can be met at the USEPA "Gold Book" recommendation of 0.025 mg/l. A further refinement of total phosphorus targets utilizes concentrations of phosphorus in lakes within uniform ecological regions (the ecoregion approach). The phosphorus concentrations predicted for White Island Pond from the Griffith et al. (1994) and Rohm et al., (1995) ecoregion maps range between 0.010 and 0.019 mg/l for typical summer to fall conditions. The United Stated Environmental Protection Agency (USEPA) has proposed a lower TP concentration for lakes in Ecoregion XIV (including White Island Pond) of 0.008 mg/l (http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/files/sumtable.pdf).

Clear water seepage lakes tend to have lower total phosphorus concentrations than typical lakes with inlet streams. The median summer surface total phosphorus concentration in other relatively unimpacted clear water seepage lakes in southeastern Massachusetts is very low (Table 4). However, White Island Pond is fairly shallow and supports a warm water fishery and, therefore, a somewhat higher total phosphorus target may be justified. Thus the target is set at the upper range of the Griffith et al., (1994) and Rohm et al., (1995) ecoregion concentrations for this area, specifically, 0.019 mg/l as an overall average for the two basins. In order to ensure that the lake meets water quality standards, the overall average should be lower than the 0.025 mg/l Gold Book number and is set to 0.019 mg/l as a margin of safety.

Table 4. Other Seepage lakes in southeastern Massachusetts

Lake name	**Town**	**Year sampled**	**TP mg/l (median surface)**
New Long Pond	Plymouth	2000	0.006
Ryder Pond	Truro	2004	0.010
Long Pond	Brewster	2004	0.016
Sheep Pond	Brewster	2004	0.005
Great Pond	Eastham	2004	0.014
Ezekiel Pond	Plymouth	2007	0.006

Loading Capacity

For purposes of this TMDL the annualized total phosphorus loading capacity target will be calculated as the mean of the lake models predictions that meet the 0.019mg/l target concentration. The parameters used are those listed in Table 2 with the new target (0.019 mg/l) inserted and the models (including the mass balance model) rerun to predict the phosphorus loads. The highest and lowest estimated loads were dropped as potential outliers, and the loading capacity is based on the mean of the remaining four models, which was 147 kg/year or 0.40 kg/day. Once the loading capacity, or TMDL, is obtained, the next step is to allocate the loads to the sources.

Wasteload Allocations, Load Allocations and Margin of Safety

The TMDL is the sum of the wasteload allocations (WLA) from point sources (e.g., sewage treatment plants and urban stormwater and agricultural discharges from point sources such as pipes or ditches) plus load allocations (LA) from nonpoint sources (e.g., landuse sources) plus a margin of safety (MOS). Thus, the TMDL can be written as:

TMDL = WLA + LA + MOS

The TMDL process requires that loads be allocated to point and non-point sources. Pipe discharges from agricultural irrigation return water are not regulated as point sources, thus all sources to White Island Pond will be considered as non-point sources. The total loading capacity of 147 kg/year represents the Total Maximum Daily Load expressed on a yearly basis. The TMDL expressed as a daily load is 147 kg/year divided by 365 days, or an average of 0.40 kg/day. However, because of the long retention time of the lake (207 days from Table 2), a yearly representation of the load is more appropriate to use. The allocation of the 147 kg/year TMDL must be reasonable and equitable and the proposed allocation is shown in Table 5. The approach used is to target anthropogenic loads that can be reduced in a cost effective manner by appropriate best management practices. Generally, the largest anthropogenic loads will be targeted for the largest reductions with all other things being equal. The individual source allocations are given below.

Loading Allocation to Nonpoint Sources

Table 5 lists the current TP loading and target TP load allocations. The groundwater is already low in concentration compared to the target concentration cannot be expected to be further reduced and the loading should remain at 50 kg/year. Although precipitation (including dry deposition) of phosphorus is influenced by anthropogenic activities to some extent, the allocated 35 kg/yr is not markedly higher than background and it is not reasonable to believe significant reductions can be made to this allocation. Private septic systems are an anthropogenic source that can be targeted for reductions as discussed in the implementation section below. Assuming some of the homes have older style septic systems, a reasonable level of reduction is 50 percent provided this reduction is implemented incrementally over a period of years as areas are sewered or properties are gradually upgraded to Title 5 systems and any non-conforming septic systems are required by the Board of Health to be upgraded. Therefore, the target allocation for septic systems is set to 28 kg/year. Internal sources may be considered partially a legacy of past anthropogenic inputs. Because internal sources of phosphorus increase as a result of anoxia associated with anthropogenic eutrophication, it can reasonably be assumed that internal sources will decline proportionately as external loading of phosphorus decreases. Given that the overall TMDL requires a decrease from 539 kg/year to 147 kg/year, or a 72 percent reduction, the internal source is similarly targeted for a 72 percent reduction for a target load of 5 kg/year.

The major sources of phosphorus are the load allocations attributed to the commercial cranberry bogs which discharge phosphorus directly into the lake. These findings are similar to an earlier study comparing housing and cranberry nutrient inputs in Wisconsin (Garrison and Fitzgerald, 2005). A previous study by MassDEP also found that commercial cranberry bogs exported large percentages (15-57%) of the phosphorus applied to the bogs and the discharge was greater than a nearby freshwater wetland (Gil, 1989).

The commercial bogs are large, anthropogenic sources of phosphorus and offer the greatest opportunity to achieve the TMDL goal. The new allocations are based on the bogs achieving an overall loading rate of 0.5 kg/ha/year achieved by the best performing bogs in the DeMoranville and Howes (2005) study. Multiplying the 0.5 kg/ha/year by the respective areas of the bogs gives a target allocation of 9 kg/year for A.D. Makepeace bogs and 10 kg/year for the Federal Furnace bogs as shown in Table 5. The excess additional bog loadings are targeted for elimination as discussed in the implementation section below.

Margin of Safety

The margin of safety is set by establishing a target that is below that expected to remove algal blooms and meet the visibility target of 4 feet for swimming and below the concentration levels needed to maintain designated uses. An additional margin of safety can be added as an explicit loading term. Based on allocations to point and the nonpoint sources, a load of 9 kg/year remains unallocated and this amount is added as an additional margin of safety.

Table 5. White Island Pond TMDL Load Allocation

Source	Current TP Loading (kg/yr)	Target TP Load Allocation (kg/yr)
Load Allocation		
Groundwater	50	50
Precipitation	35	35
Home Septic systems	56	28
Internal Sediment	18	5
Makepeace Bogs	180	9
Federal Furnace Bogs	200	10
Additional Margin of Safety	0	9
Total	539	147

Implementation

Implementation of the TMDL will focus on the largest sources, the cranberry bog discharges as shown in Table 5. Additional implementation will include upgrading failed Title 5 septic systems as required by law or by sewering areas as development increases. The groundwater is already at background concentrations and is not likely to be improved. There are no reasonable BMPs available to significantly reduce atmospheric precipitation and dryfall inputs. The internal sediment source is estimated to be small and is expected to decline as inputs to the lake are reduced.

Cranberry Bogs

Current practices used by commercial cranberry growers intended to achieve maximum crop yield can have unintended negative impacts on the surface waters that receive discharge water from the bogs. MassDEP is currently working with the UMass Cranberry Station and the Cape Cod Cranberry Growers Association to update recommended BMPs to ensure Water Quality Standards are met. For this TMDL the following BMPs may be required to meet the target allocations. The implementation will apply adaptive management in a series of steps (from simple cost saving BMPs to progressively more intensive BMPs) implemented over a period of years to evaluate the water quality response in the lake. The implementation plan for reducing total phosphorus discharges from the commercial cranberry bogs will begin with source reduction in the form and amounts of fertilizers applied and improvements to irrigation and flood water usage. As an added benefit, the reduction in fertilizer use should also result in a cost savings for the grower who no longer has to purchase unneeded fertilizer. In order to meet the TMDL, the bogs are targeted for loading reductions to the equivalent of 0.5 kg/ha/yr (0.45 lb/ac/yr) export. Based on the acres of bogs the allocation is 9 and 10 kg/year for the A.D. Makepeace and Federal Furnace bogs, respectively

This level of phosphorus export can be achieved by combining water conservation to limit final discharge rates to 3.5 acre-feet per acre of bog (see below) with average total phosphorus concentrations of 0.05 mg/l (the acceptable concentration to inputs to lakes from USEPA, 1986 "Gold Book"). A plot of phosphorus export versus phosphorus fertilizer suggests that exports can be dramatically reduced with reductions in phosphorus fertilizer application while maintaining crop yields (see Appendix III). In fact, some bogs can show zero export or even negative phosphorus export (uptake of phosphorus) while maintaining good yields by reducing phosphorus fertilizers (DeMoranville and Howes, 2005; DeMoranville et al., 2008). The key to maintaining yields is to supply the correct amount of nitrogen (generally the limiting nutrient for cranberries) while reducing the phosphorus in the fertilizer. This is accomplished by switching from low ratios of N:P:K to higher N fertilizers with proportionately less P. Commercial cranberry growers have used high ratios in the past (bags labeled 10-12-24, 10-20-20 or even 5-15-30) where the ratio of N to P_2O_5 on the bag is 1:1.2 or 1:2 or 1:3 (Howes and Teal, 1995) and this supplies too much phosphorus for plant growth needs. The recent UMass study recommends products with bag ratios of 18-8-12 or 15-15-15 (DeMoranville and Howes, 2005). In order to deliver sufficient nitrogen to the crop while reducing phosphorus applications to a target of 10 lb/ac/year phosphorus fertilizer with a N:P ratio of 2:1 such as 18-8-12, or even lower P fertilizer would be required.

Manipulation of water usage is also critical for reducing the phosphorus loading to receiving waters. In order to meet the TMDL loading targets the final yearly discharge of water should be limited to 3.5 feet of water per acre bog at a concentration of 0.05 mg/l TP or less. Other combinations of discharge and concentrations are also acceptable if they are demonstrated to meet the TMDL load. Excess water use results in excess water discharge with resulting excess leaching of phosphorus from the bogs. Irrigation water should be recycled from water stored in the bog ditches or in storage ponds to the greatest extent possible. During harvest the harvest water should also be recycled from section to section rather than flooding the entire bog complex at one time. After harvest the water should be retained in the bog complex for at least 1 to 3 days to allow particulate matter to settle out, but always less than 10 days to avoid excess release from sediments. Water should be discharged slow enough to minimize turbulence and erosion within the bogs. When possible, the discharge should be directed away from sensitive surface waters, particularly in the growing season. Winter floods should be withdrawn beneath newly formed ice within 10 days to avoid anoxic injury to plants and anoxic release of phosphorus from the flooded soils. Additional treatment and alternatives to winter flood discharges should be considered to meet the TMDL loading requirements. Monitoring of discharges is essential to ensure the TMDL load is being met.

If reductions in fertilizer application and water use fail to achieve discharge concentrations of 0.05 mg/l and loadings at or below 0.5 kg/ha/year, then additional BMPs are required. These may include the use of tailwater recovery for reuse within the bogs, pumping discharge water to other areas away from the lake, or the use of holding (detention) ponds that can be treated before discharge to public surface waters (DeMoranville and Howes, 2005). If the detention pond discharge still exceeds 0.05 mg/l, then discharges may require treatment with alum and sodium aluminate or other aluminum or iron compounds to bind and remove phosphorus prior to discharge to public waters (Leytem and Bjorneberg, 2005). If sufficient area is not available to build a detention ponds, a system of infiltration ditches lined with iron rich sand could be designed to treat the water before discharge to the pond. A similar 'iron curtain' has been used successfully to filter out phosphorus entering Ashumet Pond on Cape Cod; see: (http://toxics.usgs.gov/topics/rem_act/phosphorus_plume.html).

It should be noted that both A.D. Makepeace and Federal Furnace cranberry companies have implemented some of these BMPs as of 2008. They have stated that they are using low phosphorus fertilizers at low application rates. In addition, Federal Furnace has been pumping water to areas away from the lake and thus reduce summer and fall discharges to the lake.

Because of the large build up of excess phosphorus in cranberry bog soils, soil tests often show very high TP concentration that do not relate to crop yields and plant tissue tests may be more appropriate for determining fertilizer needs (DeMoranville and Davenport, 1997). Because of the high phosphorus in the soils, there may be a delayed response to the reductions in phosphorus fertilizer inputs and water discharges from the bogs. It is recommended that after fertilizers have been reduced to 10 lbs/acre/year and the water reuse BMPs have been initiated and the TMDL requirements met, that a period of at least 5 years elapse before any further and potentially more expensive in-lake BMPs be initiated. Recent studies on commercial cranberry bogs have shown that reduced phosphorus fertilizer application led to increased yield of cranberries while reducing TP concentrations in discharge water (DeMoranville et al., 2009). Additional studies on plots have shown there was no justification for using high phosphorus fertilizers. Even the zero phosphorus plots showed no signs of deficiency after 6 years of study (Roper, 2009).

Control of Other Sources

Implementation of other nonpoint source phosphorus reductions focuses on private septic systems and the internal load from the sediments. As noted above, the internal sediment source is considered to be largely self limiting as reducing loading will result in reduced recycling of sediment phosphorus. If future studies indicate internal sources to be larger than estimated here then an alum treatment could be considered for the pond. This would only be recommended after the major cranberry bog BMPs have been implemented as listed above.

The control of septic system input to reduce loadings by 50 percent may be difficult. Generally, the soils in the White Island Pond system are already efficiently binding phosphorus as noted above. Older homes with old style cesspools may be contributing disproportionate amounts of phosphorus to the groundwater near the lake. All home septic systems are required to be inspected upon sale for Title 5 compliance and to upgrade the system as required.

Another possibility for reducing the loading from septic systems is to sewer the area and thus divert phosphorus loadings to a wastewater treatment plant where it can be removed prior to discharge at a remote location. Opportunities for sewering the area may occur as developers are required to reduce nutrient loadings in the area to compensate for additional loadings of new home construction in an effort to meet other TMDLs, such as nitrogen TMDLs related to salt water estuaries. The densely populated area along the western shore of the West Basin is a potential area for sewering and this would completely eliminate the septic system phosphorus loads to the lake from those homes. A combination of these efforts is predicted to meet the 28 kg/year allocation target.

The shoreline areas of White Island Pond in both the towns of Wareham and Plymouth are included as urbanized areas and should be included in the NPDES Phase II stormwater permit for to the towns. The NPDES permits require six minimum control measures including public education, public participation, illicit discharge detection and elimination, construction site runoff control, post construction runoff control, and good housekeeping at municipal operations. The latter 'good housekeeping' control should include BMPs and a schedule of activities to control pollution. The permits also require the development of a stormwater management plan that must include mapping outfalls to receiving waters. Details on the Phase II permits are available at: http://www.mass.gov/dep/brp/stormwtr/stormhom.htm .

Responsibilities for Implementation

MassDEP has broad authority to enforce existing water laws and regulations that relate to water use and water quality. The Commonwealth has provided a strong framework to encourage watershed management through the recent modifications to on-site septic system regulations under Title 5 and by legislation requiring low phosphorus detergents.

The MassDEP will be responsible for obtaining public comment and support for this TMDL. The proposed tasks and responsibilities for implementing the TMDL are shown in Table 6. The local citizens within the watershed will be encouraged to locate and describe additional sources of erosion and phosphorus within the watershed following methods described in the MassDEP guidebook "Surveying a Lake Watershed and Preparing and Action Plan" (DEP, 2001) available at: http://www.mass.gov/dep/public/lwsguide.pdf.

Responsibility for remediation of each identified source will vary depending on land ownership, local jurisdiction and expertise. For example, the lake association or the Town may organize a septic tank pumping and inspection program for all lakeside homeowners. Usually a discount for the pumping fee can be arranged if a large number of homeowners apply together. Cranberry growers can apply for money to implement BMPs as part of the NRCS programs in soil conservation. Town public works departments will generally be responsible for reduction of erosion from town roadways and urban runoff. The Conservation Commission and Building Inspector will generally be responsible for ensuring the BMPs are being followed to minimize erosion from construction within the town. BMPs for general nonpoint source pollution control are described in a manual by Boutiette and Duerring (1994), BMPs for erosion and sediment control are presented in MassDEP (1997). See the web site http://www.mass.gov/dep/water/resources/watershe.htm for many of these publications. There is an Unpaved Roads BMP Manual and general information on nonpoint source BMPs at http://www.mass.gov/dep/water/resources/nonpoint.htm. A description of potential funding sources for these efforts is provided in the Program Background section, above.

A proactive approach to protecting the lake may include limiting development, particularly in areas near the lake, changes in zoning laws and lot sizes, requirements that new developments and new roadways include BMPs for runoff management and more stringent regulation of septic systems. As new housing development expands within the watershed, additional measures are needed to minimize the associated additional inputs of phosphorus. Although over fertilization of lawns was not apparent based on visual examination, homeowners should be encouraged to support a phosphorus lawn fertilizer ban as a town bylaw similar to that passed in Webster Massachusetts to reduce future phosphorus loadings from that source (http://www.articlearchives.com/government-public-administration/elections-politics/513475-1.html). Additional town bylaws to address fertilizer use and discharges to waters within the town may be required. Examples of town bylaws for zoning and construction, as well as descriptions of BMPs are presented in the Nonpoint Source Management Manual by Boutiette and Duerring (1994) that was distributed to all municipalities in Massachusetts. Other voluntary measures may include encouraging the establishment of a vegetative buffer around the lake. Such BMPs provide enhancements that residents should find attractive and, therefore, should facilitate voluntary implementation.

MassDEP is recommending that the lake be monitored on a regular basis, and if the lake does not meet the water quality standards additional implementation measures may be required. For example, if phosphorus concentrations remain high after watershed controls are in place, then in-lake control of sediment phosphorus recycling or control of other sources may be considered.

As phosphorus concentrations in the lake are reduced and transparency of the lake increases an increase in the growth of rooted aquatic plants is expected as increased light reaches the sediments. Reducing the supply of nutrients will not in itself result in achievement of all the goals of the TMDL and continued macrophyte monitoring and appropriate management is an essential part of the implementation plan.

Table 6. TMDL Tasks and Responsibilities

Tasks	**Responsible Group**
TMDL development	MassDEP
Develop Cranberry Farm Plan, fertilizer type and rates and water management BMPs that meet TMDL requirements	Cranberry Growers in concert with NRCS, Soil Conservation Service
Develop implementation approach to support the TMDL	MassDEP
Provide documentation of discharge monitoring and reasonable assurance that	Cranberry Growers

TMDL is being met	
Approve of yearly monitoring data.	MassDEP
Ensure that noncompliant septic systems are upgraded to meet Title 5 requirements	Board of Health and homeowners
Monitor chlorophyll, Secchi disk transparency and total phosphorus in lake	MassDEP and lake association
Organize and implement TMDL education, outreach programs, write grant and loan funding proposals and develop lake management plan	Local Lake Association and Town working with consultants
Implement Phase II BMPs, twice yearly road sweeping, catchbasin inspection and maintenance, install infiltration or other BMPs	Town of Plymouth and Wareham in urbanized areas
Pass town bylaws to control development, erosion from all lands, driveways and control fertilizer use	Town Selectmen, town meeting

Reasonable Assurances

Reasonable assurances that the TMDL will be implemented include both enforcement of current laws and regulations, availability of financial incentives, and the various local, state and federal program for pollution control. Active cooperation of the cranberry growers and the Cape Cod Cranberry Growers Association, homeowners, the towns of Plymouth and Wareham, USEPA, NRCS and the UMass Cranberry Station is required for this TMDL to be effective in returning the lake to an unimpaired status.

MassDEP is responsible for the implementation and enforcement of the laws related to discharges of pollution, including any nonpoint sources, under authority of Massachusetts General Laws M.G.L. c.21§§ 26-53 and the Massachusetts Surface Water Quality Standards at 314 CMR 4.00 and the Groundwater Discharge Permit Program at 314 CMR 5.00. MassDEP is also responsible for the implementation and enforcement of M.G.L. c.91 and the Waterways Regulations at 310 CMR 9.00. Enforcement of regulations may include USEPA enforcement of the permit conditions Stormwater Phase II permits under NPDES. The Commonwealth of Massachusetts also oversees the implementation of the Title 5 regulations of onsite septic systems by the local Board of Health.

Financial incentives include Federal monies available under the 319(h) NPS program and the 604(b) and 104(b) programs, which are provided as part of the Performance Partnership Agreement between MassDEP and the USEPA. Additional financial incentives include state income tax credits for Title 5 upgrades, low interest loans for Title 5 septic system upgrades, Clean Water Act State Revolving Fund loans, and cost sharing for agricultural BMPs under the Federal NRCS program.

Water Quality Standards Attainment Statement

The proposed TMDL, if fully implemented, will result in the attainment of all applicable water quality standards, including designated uses and numeric criteria for each pollutant named in the Water Quality Standards Violations noted above.

Monitoring

Continued monitoring of the lake by the local lake association should document changes in transparency and frequency of blue-green algal blooms. MassDEP will provide oversight of discharges to document phosphorus concentrations and the lake response. The toxic Bluegreen algae (cyanobacteria) numbers have been monitored in the past by MassDEP and the Massachusetts Department of Public Health will continue as needed. Additional lake surveys by MassDEP in future years, as resources allow, should include Secchi disk transparency, nutrient analyses, temperature and oxygen profiles and aquatic vegetation maps of distribution and density. At that time the strategy for reducing plant cover and reducing total phosphorus concentrations can be re-evaluated and the TMDL modified if necessary. Additional monitoring of total phosphorus concentrations by local volunteer groups is encouraged.

Public Participation

MassDEP has met with the Cape Cod Cranberry Growers Association and the UMass Cranberry Station to develop an agreed upon scope for research that resulted in the DeMoranville and Howes (2005) report on phosphorus use and discharge in commercial cranberry bogs. MassDEP has met and cooperated with the representatives of the commercial cranberry bogs. MassDEP has also met and cooperated with Mr. Jim Sullivan of the White Island Pond Conservation Alliance on sampling the pond in 2007 and monitoring of toxic cyanobacterial blooms in the lake. Additional meetings with the above named groups is ongoing.

Public Comment and Reply

Public comments will be received at the public meeting (to be scheduled) and comments received in writing within a 15 day comment period following the public meeting will be considered by the Department. The final version of the report will include both a summary of comments and the Departmental replies. The final report will be sent to U.S. EPA Region 1 in Boston for final USEPA approval.

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Appendix I Lake Data

The East and West Basins of White Island Pond were monitored during July through September, 2000 as part of a baseline survey. Both basins were also samples in 2007 on a monthly basis from June through October. The lake surveys were conducted to provide information on the current chemical, physical and biological conditions of the lake system (i.e. in-lake and in the surrounding watershed). In addition, the surveys were conducted during the summer and early fall to coincide with maximum growth of aquatic vegetation, highest recreational use, and highest lake productivity.

The 2000 baseline survey consisted of monthly sampling of water at a deep hole station in each basin. *In situ* measurements using the Hydrolab® (measures dissolved oxygen, water temperature, pH, conductivity, and depth and calculates total dissolved solids and % oxygen saturation) were recorded. At the deep hole stations measurements were recorded at various depths creating profiles. In-lake samples were also collected for alkalinity, total phosphorus, apparent color, and chlorophyll *a* (an integrated sample). Samples of the cranberry bog water were also collected and analyzed for TP and Soluble Reactive Phosphorus (SRP). Procedures used for water sampling and sample handling are described in the *Grab Collection Techniques for DWM Water Quality Sampling Standard Operating Procedure* and the *Hydrolab® Series 3 Multiprobe Standard Operating Procedure* (MassDEP 1999b and MassDEP 1999c). The Wall Experiment Station (WES), the Department's analytical laboratory, supplied all sample bottles and field preservatives, which were prepared according to the WES *Laboratory Quality Assurance Plan and Standard Operating Procedures* (MassDEP 1995). Samples were preserved in the field as necessary, transported on ice to the MassDEP Wall Experiment Station (WES), and analyzed according to the WES Standard Operating Procedure (SOP). Both quality control samples (field blanks, trip blanks, and split samples) and raw water quality samples were transported on ice to WES on each sampling date; they were subsequently analyzed according to the WES SOP. Apparent color and chlorophyll *a* were measured according to standard procedures at the MassDEP DWM office in Worcester (MassDEP 1999d and MassDEP 1999e). An aquatic macrophyte survey was conducted in August. The aquatic plant cover (native and non-native) and species distribution was mapped and recorded. Details on procedures used can be found in the *Baseline Lake Survey Quality Assurance Project Plan* (DEP DWM 1999a).

The same deep hole stations were sampled again in 2007 for the multi-probe parameters, Secchi disc transparency, chlorophyll a, color and TP. Samples were taken of the discharge flows from the cranberry bogs. Sampling details are available in the Quality Assurance Project Plan (DWM, 2007). Sampling was conducted in accordance with the procedures noted above.

Data from the surveys is presented in the tables below.

Macrophyte surveys are typically conducted during the late summer at the peak of macrophyte growth (generally in July/August/September). The macrophyte data are used in several ways:

1. to determine if the macrophyte growth causes nuisance conditions such that the lake would be listed or delisted on the state's 303d list for violations of water quality standards;
2. to determine if the lake meets designed uses in the 305b assessments;
3. to monitor changes in density of plant growth following implementation of a TMDL;
4. to document invasive species distributions in the state, and
5. to suggest macrophyte management options for the lake.

The data are used to validate Total Maximum Daily Load (TMDL) phosphorus loading models and to document the present trophic conditions as well as assessing the status of lake's designated uses. The total phosphorus data are used to evaluate accuracy of land use loading estimates (Mattson and Isaac 1999) of total phosphorus to lakes by comparing predictions of lake concentrations based on modeling to actual measured lake concentrations. These may be used as a basis for estimation of internal loading or other unmeasured phosphorus sources. Concurrently a lake database will be developed for both 303d development and for 305b evaluation based on lakes that are on the current 303d list. The data contained in this database along with the other data collected are used in TMDL development or to monitor lakes for changes in water quality and nuisance plant growth after TMDL implementation.

Table 7. Hydrolab data Baseline Lake Monitoring, 2000.

White Island Pond (Palis: 95166)
Unique_ID: 762   Station: A
Description: deep hole in southern lobe of East Basin, Plymouth

Date	OWMID	Time	Depth	Temp	pH	Cond@ 25C	TDS	DO	SAT
		(24hr)	(m)	(C)	(SU)	(uS/cm)	(mg/l)	(mg/l)	(%)
7/19/2000									
	LB-0656	10:02	0.5	24.4	6.4	49.4	31.6	7.8	92
		10:11	1.4	24.3	6.3	49.3	31.6	7.6	89
		10:17	2.5	24.2	6.3	49.1	31.4	7.2	85
		10:23	3.4	24.2	6.2	49.1	31.4	7.2	84
		10:30	3.9	24.2	6.2	49.2	31.5	7.1	83
8/16/2000									
	LB-0747	14:13	0.5	22.7	6.8u	46.9	30.0	9.0	103
		14:17	1.5	22.7	6.7	46.9	30.0	8.9	101
		14:22	2.5	22.7	6.7	46.9	30.0	8.8	101
		14:26	3.7	22.7	6.6	47.1	30.1	8.5u	96u
9/20/2000									
	LB-0836	12:57	0.5	21.2	7.3ci	46.4	29.7	9.4	105
		13:04	1.5	21.2	7.1ci	46.4	29.7	9.3	103
		13:10	2.5	21.1	6.6i	46.4	29.7	9.0	100
		13:16	3.5	21.0	6.0i	47.0	30.1	**u	**u
		13:23	4.0	20.7	5.8i	48.1	30.8	5.2u	57u

White Island Pond (Palis: 95173)
Unique_ID: 754   Station: A
Description: deep hole in northern lobe of West Basin, Plymouth

Date	OWMID	Time	Depth	Temp	pH	Cond@ 25C	TDS	DO	SAT
		(24hr)	(m)	(C)	(SU)	(uS/cm)	(mg/l)	(mg/l)	(%)
7/19/2000									
	LB-0657	11:40	0.5	24.8	6.0	48.5	31.0	7.7	91
		11:46	1.5	24.8	6.1	48.6	31.1	7.7	91
		11:52	2.5	24.9	6.0	48.6	31.1	7.6	90
		11:59	3.5	24.9	6.1	48.7	31.1	7.6	90
8/16/2000									
	LB-0751	12:50	0.5	23.2	6.0	46.8	29.9	7.9	91
		13:00	1.5	23.2	6.0	46.8	29.9	7.9	90
		13:03	2.5	23.2	5.9	46.8	29.9	7.8	90
		13:08	3.5	23.2	5.9	46.8	29.9	7.8	90
	LB-0975	13:16 m	3.5m	23.2 m	6.0 m	46.8m	29.9 m	7.8m	90m
		13:20 m	2.5m	23.2 m	6.0 m	46.8m	29.9 m	7.9m	91m
		13:24 m	1.5m	23.2 m	6.0 m	46.7m	29.9 m	7.9m	91m
		13:29 m	0.5m	23.2 m	6.0 m	46.8m	29.9 m	7.8m	90m
9/20/2000									
	LB-1167	15:00	0.5	22.1	7.0u	46.2	29.6	9.4	106
		15:06	1.5	22.0	7.0	46.4	29.7	9.3	105
		15:12	2.5	21.9	6.6	46.3	29.6	9.2	104
		15:19	3.5	21.5	5.7	46.9	30.0	6.9u	77u

Table 8. Water Quality Data. Baseline Lake Monitoring, 2000 .

East White Island Pond (Palis: 95166)
Unique_ID: W0762   Station: A
Description: deep hole in southern lobe of East Basin, Plymouth

Date	Secchi	Secchi Time	Station Depth	OWMID	Sample Depth	Relative Depth	Alkalinity	TP	Apparent Color	Chl a
	(m)	24hr	(m)		(m)		(mg/l)	(mg/l)	PCU	(mg/m3)
7/19/2000	1.2	10:30	4.5							
				LB-0645	0.5	Surface	3	0.12	--	--
				LB-0646	0.5	Surface	4	0.098	--	--
				LB-0648	0 - 3.6	Integrated	--	--	--	** m
				LB-0649	**m	Near Bottom	4m	0.099m	--	--
8/16/2000	1.1	14:07	4.3							
				LB-0738	0.5	Surface	4	0.085	--	--
				LB-0739	0.5	Surface	4	0.084	--	--
				LB-0740	0.5	Surface	4	0.093	--	--
				LB-0741	3.7	Near Bottom	4	0.089	--	--
				LB-0743	0 - 3.7	Integrated	--	--	--	35.4
9/20/2000	1.1	12:35	4.5							
				LB-0832	**m	Surface	2	0.077	23	--
				LB-0833	**m	Surface	2	0.077	23	--
				LB-0834	**m	Near Bottom	2m	0.080m	17m	--
				LB-0835	0 - 4.0	Integrated	--	--	--	35.5 h

West White Island Pond (Palis: 95173)

Unique_ID: W0754 Station: A
Description: deep hole in northern lobe of West Basin, Plymouth

Date	Secchi	Secchi Time	Station Depth	OWMID	Sample Depth	Relative Depth	Alkalinity	TP	Apparent Color	Chl a
	(m)	24hr	(m)		(m)		(mg/l)	(mg/l)	PCU	(mg/m3)
7/19/2000	2.0	11:45	4.0							
				LB-0652	0.5	Surface	2	0.076	--	--
				LB-0653	3.5	Near Bottom	<2	0.048	--	--
				LB-0654	0 - 3.5	Integrated	--	--	--	5.7
8/16/2000	2.2	12:30	4.0							
				LB-0748	0.5	Surface	4	0.038	--	--
				LB-0749	3.5	Near Bottom	3	0.037	--	--
				LB-0750	0 - 3.5	Integrated	--	--	--	11.8
9/20/2000	1.3	14:30	4.0							
				LB-0849	0.5	Surface	<2	0.038	<15	--
				LB-1165	3.5	Near Bottom	2	0.037	<15	--
				LB-1166	0 - 3.5	Integrated	--	--	--	13.1 h

Table 9. Water Quality Data. Baseline Lake Monitoring, 2007.

East White Island Pond (Palis: 95166)
Unique_ID: W0762 Station: A
Description: deep hole in East Basin, Plymouth **DATA from 2007 fieldsheet/WES Lab report**

Date	Secchi	Secchi Time	Station Depth	OWMID	Sample Depth	Relative Depth	TP	Chl a
	(m)	24hr	(m)		(m)		(mg/l)	(mg/m3)
6/26/2007	1.3	14:15	4.9	LB-3901	0.2	Surface	0.052	
				LB-3902	0.2	Surface	0.053	
				LB-3903	3.9	Near Bottom	0.076	
				LB-3904	0-3.9	Integrated	-	20.4
				LB-3905	0-3.9	Integrated	-	20.2
7/25/2007	1.0	11:00	4.6					
				LB-3942	0.2	Surface	0.072	
				LB-3943	0.2	Surface	0.068	
				LB-3944	3.6	Near Bottom	0.067	
				LB-3946	0-3.6	Integrated	-	47.8
				LB-3947	0-3.6	Integrated	-	45.0
8/21/2007	0.8	11:40	4.7					
				LB-3982	0.2	Surface	0.094	
				LB-3983	0.2	Surface	0.095	
				LB-3984	3.7	Near Bottom	0.090	
				LB-3986	0-3.7	Integrated	-	**
				LB-3987	0-3.7	Integrated	-	**
9/24/2007	0.7	11:55	4.7					
				LB-4012	0.5	Surface	0.10	
				LB-4013	0.5	Surface	0.11	
				LB-4014	3.7	Near Bottom	0.13	
				LB-4016	0-3.7	Integrated	-	62.
				LB-4017	0-3.7	Integrated	-	56.
10/18/2007				LB-4032	0.2		0.11	
				LB-4033	0.2		0.10	

West White Island Pond (Palis: 95173)
Unique_ID: W0754   Station: A
Description: deep hole in West Basin, Plymouth **DATA from 2007 fieldsheet/WES Lab report**

Date	Secchi	Secchi Time	Station Depth	OWMID	Sample Depth	Relative Depth	TP	Chl a
	(m)	24hr	(m)		(m)		(mg/l)	(mg/m3)
6/26/2007	2.0	13:15	4.6					
				LB-3913	0.2	Surface	0.029	
				LB-3914	0-3.6	Integrated	-	7.6
				LB-3915	3.6	Near Bottom	0.068	
7/25/2007	2.1	12:50	4.7					
				LB-3951	0.2	Surface	0.027	
				LB-3952	3.7	Near Bottom	0.067	
				LB-3953	0 - 3.6	Integrated	-	22.8
				LB-3954	0.2	Grab		
8/21/2007	1.6	13:22	4.4					
				LB-3991	0.2	Surface	0.042	
				LB-3992	3.4	Near Bottom	0.056	
				LB-3993	0-3.5	Integrated	-	23.4 d
9/24/2007	1.4	12:40	4.2					
				LB-4021	0.5	Surface	0.036	
				LB-4022	3.2	Near Bottom	0.044	
				LB-4023	0 - 3.2	Integrated	-	25.7
10/18/2007	1.7	12:30	4.0	LB-4041	0.2	Surface	0.035	

Table 10. Water Quality Data. Cranberry Bog Data 2007.

Federal Furnace Pipe J inlet to East White Island Pond
Unique_ID: W1600 Station: J
Description: Cranberry bog discharge pipe (approx 10 inch diameter) at eastern edge of northern lobe

Date	Secchi	Secchi Time	Station Depth	OWMID	QAQC	Sample Depth	Relative Depth	TP	SRP
	(m)	24hr	(m)			(m)		(mg/l)	(mg/l)
6/26/2007	--	132:40	--	LB-3920		--		0.68	--
10/18/2007	--	12:01	--	LB-4034		--		0.26	--

Makepeace Pipe K inlet East White Island Pond
Unique_ID: W1601 Station: K
Description: Cranberry bog discharge pipe (approx 16   inch diameter) at northwestern edge of northern lobe

Date	Secchi	Secchi Time	Station Depth	OWMID	QAQC	Sample Depth	Relative Depth	TP	SRP
	(m)	24hr	(m)			(m)		(mg/l)	(mg/l)
7/25/2007	--	10:50	--	LB-3970		--		0.078	0.034
8/21/2007	--	10:40	--	LB-3960		--		0.068	0.026

“ ** ” = Censored or missing data

“ -- ” = No data

“ b ” = **b**lank Contamination in lab reagent blanks and/or field blank samples (indicating possible bias high and false positives).

“ **d** ” = precision of field **d**uplicates (as RPD) did not meet project data quality objectives identified for program or in QAPP; batch samples may also be affected

“ **h** ” = **h**olding time violation (usually indicating possible bias low)

“ **m ”** = **m**ethod SOP not followed, only partially implemented or not implemented at all, due to complications with sample matrix (e.g. sediment in sample, floc formation), lab error (e.g., cross-contamination between samples), additional steps taken by the lab to deal with matrix complications, and lost/unanalyzed samples

Appendix II Carlson Trophic State Index (TSI)

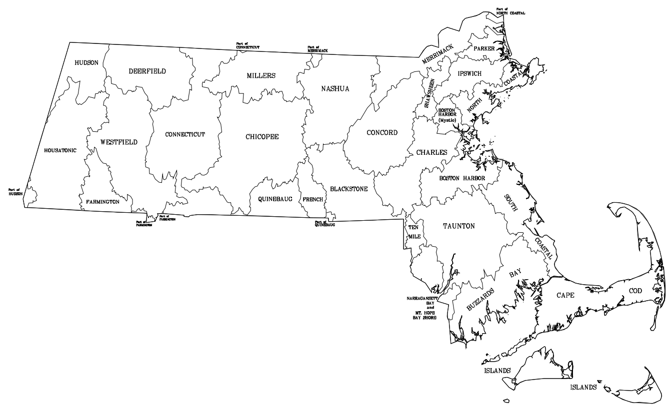
Carlson's Trophic State Index and Attributes of Lakes.
(Modified from http://dipin.kent.edu/tsi.htm#A%20Trophic%20State%20Index Carlson and Simpson (1996).

A list of possible changes that might be expected in a north temperate lake as the amount of algae changes along the trophic state gradient.

TSI	Chl (ug/L)	SD (m)	TP (ug/L)	Attributes	Water Supply	Fisheries & Recreation
<30	<0.95	>8	<6	**Oligotrophy:** Clear water, oxygen throughout the year in the hypolimnion	Water may be suitable for an unfiltered water supply.	Salmonid fisheries dominate
30-40	0.95-2.6	8-4	6-12	Hypolimnia of shallower lakes may become anoxic		Salmonid fisheries in deep lakes only
40-50	2.6-7.3	4-2	12-24	**Mesotrophy:** Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Iron, manganese, taste, and odor problems worsen.	Hypolimnetic anoxia results in loss of salmonids. Walleye may predominate
50-60	7.3-20	2-1	24-48	**Eutrophy:** Anoxic hypolimnia, macrophyte problems possible		Warm-water fisheries only. Bass may dominate.
60-70	20-56	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems	Episodes of severe taste and odor possible.	Nuisance macrophytes, algal scums, and low transparency discourage swimming and boating.
70-80	56-155	0.25-0.5	96-192	**Hypereutrophy:** (light limited). Dense algae & macrophytes		
>80	>155	<0.25	192-384	Algal scums, few macrophytes		Rough fish dominate; summer fish kills possible

Appendix III. Guidelines for Total Maximum Daily Loads of Phosphorus from Commercial Cranberry Bog Discharges in Massachusetts.

Mark D. Mattson
MassDEP TM-T-1, CN307.0, DWM February 9, 2009



<u>NOTICE OF AVAILABILITY</u>

Limited copies of this Guideline are available at no cost by written request to:
Massachusetts Department of Environmental Protection
Division of Watershed Management
627 Main Street
Worcester, MA 01608

DISCLAIMER

References to trade names, commercial products, manufacturers, or distributors in this report constitute neither endorsement nor recommendations by the Division of Watershed Management.

Introduction

The purpose of this document is to evaluate available information on the operation of commercial cranberry bogs in relation to discharges of nutrients, particularly phosphorus, into sensitive receiving waters such as freshwater lakes. The current operation of water use and fertilizer use is summarized to estimate the annual discharge of phosphorus from commercial bogs. In addition, the available information from the literature is summarized to establish new Best Management Practices for both water use, reuse and discharge as well as phosphorus fertilizer rates that are expected to result in receiving waters attaining all relevant Water Quality Standards.

Commercial cranberry production is a major crop in southeastern Massachusetts. The cranberry is a native wetland plant (*Vaccinium macrocarpon*) that is planted into bogs and fertilized like other crops. But unlike other crops, cranberries require frequent irrigation and seasonal flooding. The discharge of waters from the bogs, either from return flows from irrigation during the growing season or due to discharge of the flood waters allows nutrients such as phosphorus and nitrogen, to be discharged from the bogs to nearby or downstream surface waters. It is this large discharge of nutrient rich water that is a concern to local water quality because the nutrient can stimulate the growth of nuisance aquatic plants and algae.

Currently, many of the large recreational lakes in southeastern Massachusetts are impaired by various combinations of nutrients, noxious aquatic plants (includes algae), turbidity (due to algae blooms) and impairments of low dissolved oxygen and organic enrichment. Many of these lakes receive large discharges of water from nearby commercial bogs and these lakes are listed in the Massachusetts 2006 Integrated list (MassDEP, CN 262.1, 2007; http://www.mass.gov/dep/water/resources/2006il4.pdf) as impaired (Category 5) under Section 303d of the Federal Clean Water Act: New Bedford Reservoir in Acushnet, Noquochoke Lake in Dartmouth, Parker Mills Pond and Tihonet Pond in Wareham, White Island Pond and Billington Sea in Plymouth and Wareham, Furnace Pond and Stetson Pond in Pembroke, Wampatuck Pond in Hanson, Lower Mill Pond, Upper Mill Pond and Walkers Pond in Brewster, Santuit Pond in Mashpee, West Monponsett Pond in Halifax/Hanson.

According to the Federal Clean Water Act, the state must develop allowable nutrient budgets or Total Maximum Daily Loads (TMDLs) for these waters such that they fully support all designated uses. In addition to these there are numerous streams and coastal embayments downstream of the bogs that are also listed as impaired by nutrients. Many of the smaller lakes and streams in the region have not been assessed but may be threatened by excess nutrients because they are also located near the discharge areas of the commercial bog operations. Similar problems with lake eutrophication have been seen in Wisconsin (the leading producer of cranberries) where cranberry production was implicated as the major source of nutrients (Garrison and Fitzgerald, 2005). This report reviews the operation of the bogs and reviews the literature on fertilizer use and nutrient export from commercial bogs and natural wetlands and provides guidance for the development of total phosphorus Total Maximum Daily Loads for freshwater lakes.

Background on Commercial Bog Operations

Historically, commercial cranberry bogs were created over natural wetlands but natural wetlands have been protected since the development and revisions of the Wetlands Protection Act in Massachusetts between 1963-1972. Any new commercial bogs created in Massachusetts since that time are required to be constructed in upland areas by grading the land level and adding sand as the plant bed. A series of dikes, ditches, pumps and flumes allows for periodic flooding and sand is added to the beds as a rooting medium. Water enters as rainfall and is pumped in for frequent irrigation. In some cases surface water runoff, a natural stream or groundwater seepage may add additional water to the bogs and is also discharged as needed (i.e., a flow-through bog; see Figure 1). The fall harvest occurs by flooding the bogs to allow the berries to be knocked loose and float into collection areas. After harvest the water is discharged to nearby surface waters. Flooding also occurs temporarily during winter to allow ice formation to protect vines from freezing. Flooding may also occur at other times for insect control. Typically, commercial cranberry bogs require about 10 acre-feet of water each year for combined irrigation and flooding purposes (DeMoranville and Howes, 2005).

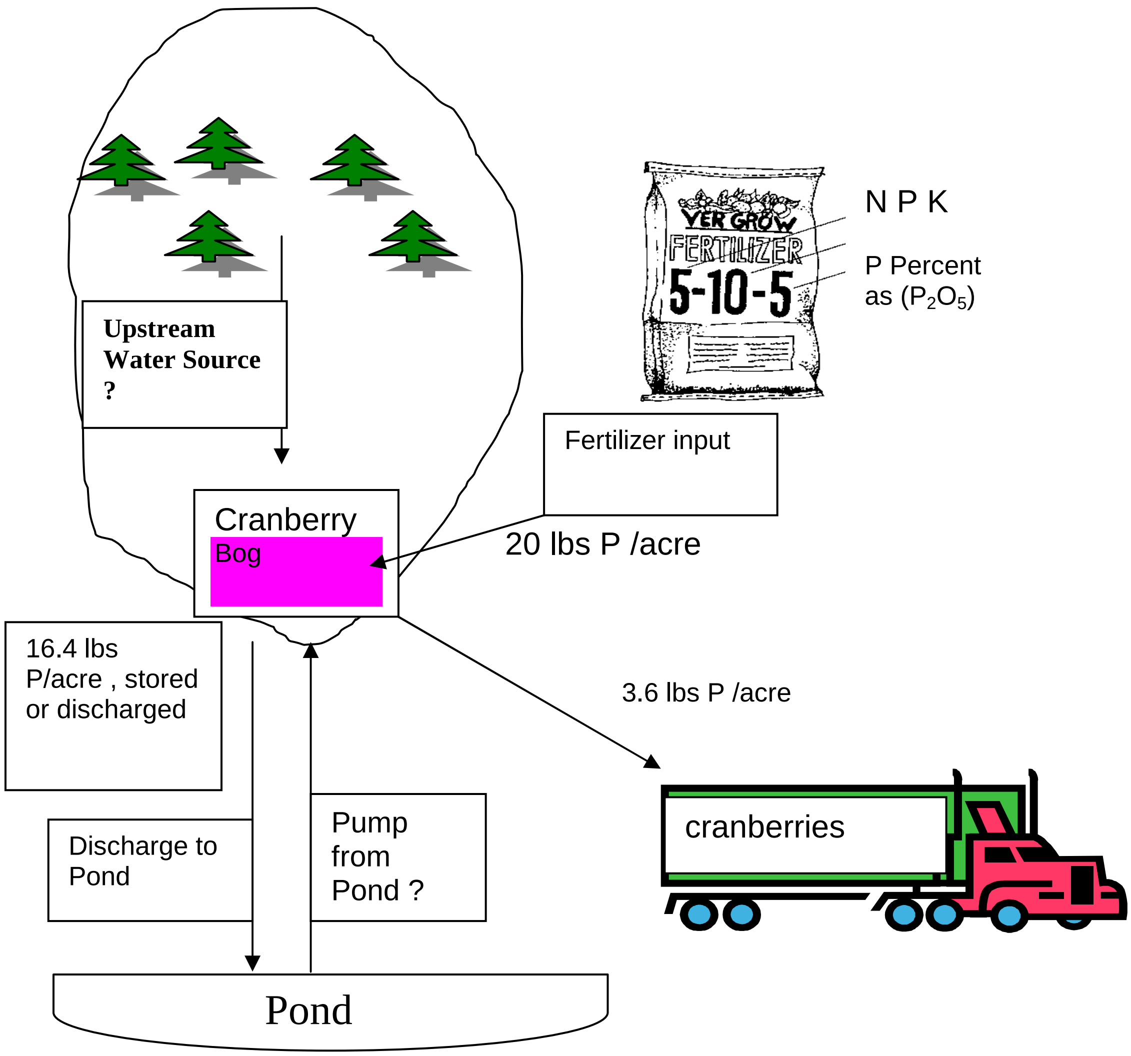


Figure 1. Schematic Diagram of a Phosphorus Budget for a Cranberry Bog.

Up until recently, the recommended phosphorus fertilizer inputs for traditional cranberry bogs has been 20 pounds per acre per year, according to the University of Massachusetts Cranberry Station publications http://www.umass.edu/cranberry/services/bmp/phosphorus.shtml although higher rates are recommended in some cases. Typical commercial bogs often use higher rates than the recommended 20 lbs/ac/yr (22.4 kg/ha/yr) as shown in Table 16 in DeMoranville and Howes, (2005). In that study, half of the bogs were applying phosphorus fertilizer at rates of 31 to 45 lbs P/ac/yr (27.9-39.8 kg/ha/yr) in the first year of the study. These rates are similar to a study of a nearby bog where the rates of phosphorus fertilizer application were 29.2 lb P/ac/yr (Howe and Teal, 1995). The harvest of berries and associated leaves and twigs removes about 3.6 pounds of phosphorus per acre each year (DeMoranville and Howes, 2005). If a bog were fertilized at the recommended rate (20 lbs/ac/yr) it implies that 16.4 pounds per acre (18.3 kg/ha/yr) are potentially available for buildup in the soil or for downstream export (see Figure 1). Over many years of excess phosphorus application soils are expected to become saturated with excess phosphorus and may start to export more phosphorus over time.

Review of Fertilizer Application and Crop Yield

Several lines of evidence are available on the phosphorus fertilizer requirements of cranberries. As noted in Roper et al., 2004, a number of early studies had identified that 22 kg/ha/yr (20 lbs/acre/yr) was sufficient for commercial cranberry operations, but the studies did not examine if lower fertilizer rates would also be sufficient. More recent studies in Massachusetts have found that yields of cranberry are not very responsive to phosphorus in fertilizer at any rate, presumably because of over fertilization in past years has built up a supply of phosphorus in the cranberry soils. These studies include the recent whole bog studies as well as smaller, but more detailed plot studies in Massachusetts (DeMoranville and Howes, 2005; DeMoranville, 2006) which found no reduction in cranberry yield as phosphorus was lowered to less than 20 lbs/acre/year and in some cases yields increased with lower or even no phosphorus applied at all. In the Eagle Holt bog fertilizer rates were reduced to 16.1 kg/ha and 6.3 kg/ha (14.3 lb/ac and 5.6 lb/ac) in 2003 and 2004, respectively, and yields actually increased by 31 percent over the previous two years (DeMoranville and Howes, 2005). The average yield for all six bogs in the first two years was 135 bbl/acre/yr, but the yield actually increased to 155 bbl./acre/yr during the next 2 years as fertilizer was reduced on the six bogs studied by DeMoranville and Howes (2005). The final recommendations of the DeMoranville and Howes (2005) study was that 20 lbs/acre/year of phosphorus fertilizer are sufficient and that typical native cranberries on organic soils may have lower targets of 10-15 lbs/acre/year unless tissue tests show deficiency (<0.1% in August).

An extended multiyear study of four of the experimental bogs also showed that the three lowest phosphorus fertilizer rates below 10 kg/ha/yr (averaging about 6 lb/ac/yr) produced cranberry yields greater than the median of all the treatments (Figure 2). These results are supported by recent work of Parent and Marchand (2006) who found there were year-to-year differences and site-to-site differences in cranberry production, but found there was no benefit to adding phosphorus on the yield of cranberries in a Quebec study. Additional studies on plots have shown there was no justification for using high phosphorus fertilizers. Even the zero phosphorus plots showed no signs of deficiency after 6 years of study (Roper, 2009).

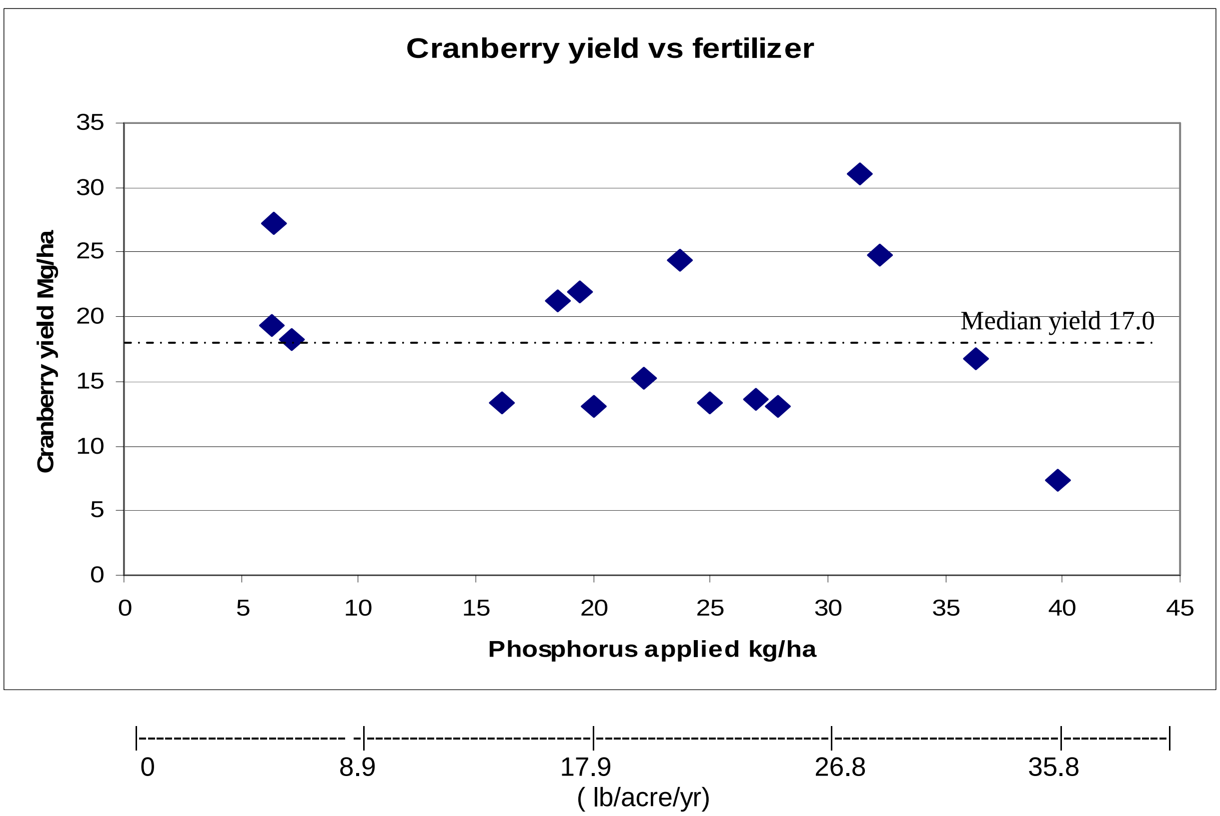


Figure 2. Cranberry yield vs. Fertilizer Rates (Data from DeMoranville et al., 2008).

Export of Phosphorus from Commercial Cranberry Bogs

There have been two recent studies on nutrient export from commercial cranberry bogs in Massachusetts. The first study (Howes and Teal, 1995), focused on a flow-thru bog while the second study (DeMoranville and Howes, 2005), was more extensive and included varying fertilizer rates, and measuring cranberry yields along with both net and gross export of nutrients from six commercial bogs over several years. Much of the following discussion will focus on the more recent study (DeMoranville and Howes, 2005).

The bogs studied by DeMoranville and Howes (2005) showed variation in export related to soil type and fertilizer rates. The two upland bogs on mineral soils (Mineral 5 and 6 in Figure 3) with essentially no discharges other than harvest discharges had total phosphorus concentrations equal to or less than 0.1 mg/l in discharge water, with resulting low export rates of about 0.5 kg/ha/yr. The typical bog in Massachusetts is probably more like the four organic bogs studied by DeMoranville and Howes (2005), which were established bogs on organic (wetland) soils with periodic discharges during the growing season as well as during harvest or winter floods. These bogs tend to have concentrations of phosphorus between 0.15 and 0.5 mg/l in the discharge water and tend to discharge about 3 kg/ha/yr (see Figure 3, Organic 1-4). The median of the organic bog net discharge in the first year (prior to major reductions in fertilizer application was 3.4 kg/ha/yr and is the best estimate of typical organic cranberry bog export in Massachusetts. Because the total discharge of water (per unit area) was similar from the series of six bogs there is a linear relationship between the net discharge of phosphorus from the bogs and the concentration of phosphorus in the discharge water (Figure 3). Lacking other information the net export from bogs can be estimated from the average total phosphorus concentration as shown in Figure 3 as: net export (kg/ha/yr) = -0.59+8.83*Conc. (mg/l), N=18, r^2=0.47, α=0.001. The flow-thru bog was reported to export large amounts of phosphorus (9.9 kg/ha/yr) with the major discharge events having phosphorus concentrations averaging 0.53 mg/l during winter floods (Howes and Teal, 1995). Recent studies on commercial cranberry bogs have shown that reduced phosphorus fertilizer application led to increased yield of cranberries while reducing TP concentrations in discharge water (DeMoranville et al., 2009).

Much of the phosphorus exported from the bogs is associated with flood discharges. In particular, flood waters held for more than about 10 days leads to anoxia and the release of phosphorus (DeMoranville and Howes, 2005).

Export of total phosphorus from natural wetlands and forested watersheds was also reviewed by DeMoranville and Howes (2005). The literature suggests that freshwater wetlands such as beaver ponds, peat soil wetlands, and wetlands bordering streams export between 0.41 kg/ha/year and 0.68 kg/ha/year (median of 0.47 kg/ha/yr), while cypress swamps and tidal saltwater marshes export higher amounts. The forested wetland system in Westport Massachusetts had a gross export of 0.14 to 0.15 kg/ha/yr of phosphorus. This is in general agreement with a review of phosphorus export from various landuses that indicates forests export an average of 0.236 kg/ha/yr, while row crops export an average of 4.46 kg/ha/yr (Reckhow et al., 1980). Thus, the overall mean fluvial export of 1.65 and 3.02 kg/ha/yr (net and gross, respectively) reported for commercial cranberry bogs by DeMoranville and Howes (2005) indicates cranberries export much larger amounts of phosphorus than forests or typical freshwater wetlands, but generally export less than agricultural row crops. Flow-through bogs may export higher amounts of phosphorus than most row crops (Howes and Teal, 1995).

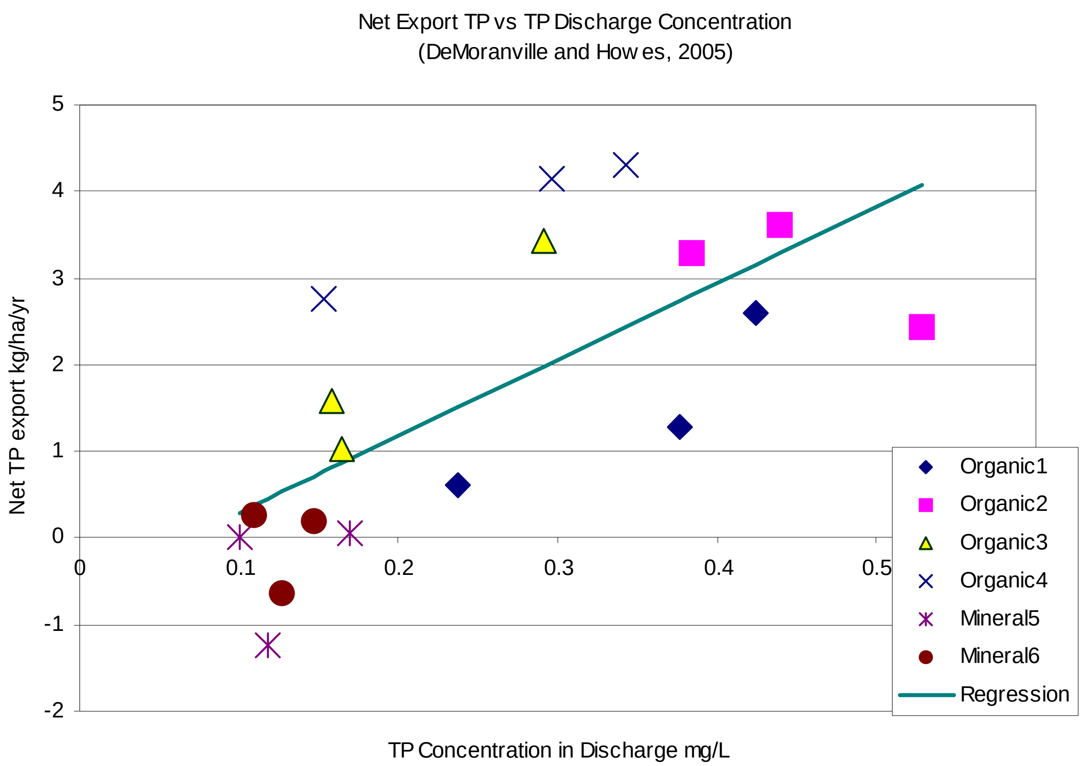


Figure 3. Net TP Export vs. TP Concentration.

Lake Nutrient Budgets

Nutrient budgets for impaired lakes require knowledge of nutrient export from local sources including point sources (discharges from pipes or other discrete sources as well as various land uses that discharge nonpoint source pollution. This report examines nutrient budgets from commercial cranberry operations within Massachusetts as diagramed in Figure 1. Nutrient budgets are typically presented both as net budgets and as gross discharge budgets and as 'fluvial budgets'. The nutrient budgets measure (or estimate) all nutrients entering the bog and all nutrients leaving the bog as shown in the schematic diagram below. Generally, the two major nutrient inputs to a bog are nutrients in the irrigation water and nutrient in the fertilizers. The two major nutrient losses from a bog are nutrients discharged in released water, and nutrients in plant materials harvested from the bog (berries as well as leaves and twigs). From a water quality standpoint we are most interested in the 'fluvial budget', that is, the amount of nutrients delivered to a lake via natural water inputs compared to the additional nutrients in discharge water that enter the bog due to commercial bog operations. Other imports to the bogs (such as fertilizers) and exports from the bog, such as phosphorus in the crop of cranberries, are accounted for outside of the fluvial budget in the total budget.

From a lake water quality point of view there are two general types of bogs and associated nutrient budgets to consider: autochthonous nutrient sources and allochthonous nutrient sources. First, where the source of bog irrigation and floodwater is a tributary to the receiving pond or is the receiving pond itself (autochthonous), the most appropriate nutrient flux is the net fluvial nutrient budget. In such bogs the original nutrients in the irrigation and flood waters was either in the lake or would have entered the lake in the absence of bog operations. In that case, the nutrients in the input source water are subtracted from the fluvial outputs to calculate the net difference. In other words the extra amount of nutrients entering the pond due to the cranberry bog operation is the net fluvial export from the bog. Corrections may be required if the source water is polluted from previous discharges from the same bog. The second case would be a bog that gets irrigation and flood water from an outside water source (allochthonous), that is, from a source that normally would not enter the receiving pond. Typically this is a groundwater well or stream or source pond that is not tributary to the receiving pond. In this case the gross fluvial export is calculated as the input to the receiving pond, because the input to the pond includes both the nutrients from the bog as well as nutrients in the original source water. The nutrients from both the water as well as nutrients derived from fertilizers are new inputs to the bog as a result of management operations.

Target loads and nutrients to maintain water quality standards.

The Massachusetts Water Quality Standards 314CMR4.05 http://www.mass.gov/dep/service/regulations/314cmr04.pdf) state conditions for best available technology (BAT) for point and nonpoint sources including publicly owned treatment works (POTWs) and other sources:

> Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses and shall not exceed the site specific criteria developed in a TMDL or as otherwise established by the Department pursuant to 314 CMR 4.00. Any existing point source discharge containing nutrients in concentrations that would cause or contribute to cultural eutrophication, including the excessive growth of aquatic plants or algae, in any surface water shall be provided with the most appropriate treatment as determined by the Department, including, where necessary, highest and best practical treatment (HBPT) for POTWs and BAT for non POTWs, to remove such nutrients to ensure protection of existing and designated uses. Human activities that result in the nonpoint source discharge of nutrients to any surface water may be required to be provided with cost effective and reasonable best management practices for nonpoint source control.

In addition, water withdrawals are regulated under the Water Management Act regulations http://www.mass.gov/dep/service/regulations/310cmr36.doc. These regulations allow for registration and/or permitting of water withdrawals for cranberry operations including regulations regarding water conservation, water quality, farming practices and reporting requirements to protect other water uses. Water withdrawals may be established under nonconsumptive use which means any use of water which results in its being discharged back into the same water source at or near the withdrawal point in substantially unimpaired quality and quantity.

As a general guideline, concentrations should not exceed 0.050 mg/l in any stream entering a lake or pond (USEPA, 1986). The USEPA has issued guidance for water quality nutrient concentrations of total phosphorus of 0.031 mg/l for rivers in southeastern Massachusetts (USEPA, 2000; http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/rivers_14.pdf.)

The lakes in southeastern Massachusetts may be considered as belonging to two general types: lakes with tributaries and seepage lakes with no tributaries. The seepage lakes are fed mainly by groundwater and direct precipitation and tend to be more oligotrophic, clear water lakes. Some seepage lakes are set in organic soils that may contribute dissolved organic compounds that color the water and this may result in higher phosphorus levels The clear water seepage lakes are thus more sensitive to nutrient inputs and generally should have lower total phosphorus concentrations. Clearwater seepage lakes in southeastern Massachusetts may reasonably be expected to have concentrations of total phosphorus of less than 0.020mg/l and possibly as low as 0.008 mg/l (MassDEP, in prep.; USEPA, 2001; http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/lakes/lakes_14.pdf).

Thus, inputs from external sources must be limited to meet the state’s Water Quality Standards and to protect designated uses. The nutrient management requirements to meet Water Quality Standards may vary depending on the receiving water but at a minimum, discharges should not exceed the EPA guideline of 0.1 mg/l for streams and the 0.05 mg/l for tributaries to lakes. By way of comparison, current National Pollutant Discharge Elimination System (NPDES) permits for typical wastewater treatment plant discharges in Massachusetts are set at 0.1 mg/l in the discharges to sensitive receiving waters. Extensive Best Management Practices will be required in order to ensure receiving waters meet the state’s Water Quality Standards.

Best Management Practices Protective of Water Quality

The data from the six commercial cranberry bogs studies in the DeMoranville and Howes (2005) study was further analyzed to examine the relationship of fertilizer rates on cranberry yields, concentrations of phosphorus in discharge waters and downstream export of nutrients. The data indicate that if most protective BMPS recommended by DeMoranville and Howes (2005) are followed, export of phosphorus from commercial bogs can be reduced with little or no impact on crop yields. Specifically, no more phosphorus than the lower range of fertilizer rates of 10-15 lbs/acre/year recommended by DeMoranville and Howes (2005) should be applied. In addition, the recommended best management of water use (using tailwater or retention ponds to remove phosphorus prior to discharge, holding floodwater 1-3 days, but less than 10 days, with slow discharge and winter flood control to minimize flood holding times to avoid anoxia) must be followed. Fertilizers must be restricted to ratios of $N:P_2O_5$ of greater than 1:1 and preferably 2:1 such as commercial 18-8-12 or 12-6-8. If discharges are to a sensitive clear water seepage bog the additional BMPS recommended by DeMoranville and Howes (2005) of installing tailwater recover or other physical barriers or filtration may be required to meet water quality standards.

If the recommended phosphorus fertilizer rates of 10-15 lb/acre/year are followed the data suggest commercial cranberry bogs will achieve net fluvial discharges of less than 1 kg/ha/year. This can typically be achieved if total phosphorus concentrations in discharge waters are at or below 0.1 mg/l (Figure 3) and/or, if increase in phosphorus concentration between source water to discharge water is held to an increase of no more than 0.032mg/l (assuming 10 acre feet of water use and no reuse of source water). If the discharge is to sensitive waters then lower export rates may be required. A discharge of 0.5 kg/ha/yr (higher than forests but lower than row crops) may be required and this could be achieved if discharge concentrations follow than the EPA 'Gold Book' (EPA, 1986) guidelines of 0.050mg/l for discharges to lakes and discharge volumes are limited to 3.3 acre-feet per acre bog per year or less.

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